รายงานวิจัยฉบับสมบูรณ์

โครงการ ระบบการแสดงข้อมูลแบบกระจายเพื่อใช้สำหรับการร่วมมือ ในการผสมและวิเคราะห์ข้อมูล

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สัญญาเลขที่ TRG4580104

รายงานวิจัยฉบับสมบูรณ์

โครงการ

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A collaborative Environment for Distributed Data Analysis and Fusion

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สนับสนุนโดยสำนักงานกองทุนสนับสนุนการวิจัย

กิตติกรรมประกาศ

ผู้วิจัย ขอขอบคุณ รศ.ดร. บุญเจริญ ศิริเนาวกุล ที่ให้คำปรึกษาและเสนอแนะในการศึกษาค้นคว้าตลอดช่วงเวลาทำงานวิจัย ขอขอบคุณภาควิชาวิศวกรรมคอมพิวเตอร์ มหาวิทยาลัยเทคโนโลยีพระจอมเกล้าธนบุรี ในการเอื้ออำนวยสถานที่และครุภัณฑ์สำหรับดำเนินงานวิจัย โครงการนี้ได้รับความอนุเคราะห์และสนับสนุนโดยสำนักงานกองทุนสนับสนุนการวิจัย

บทคัดย่อ

รหัสโครงการ TRG4580104

ชื่อโครงการ ระบบการแสดงข้อมูลแบบกระจายเพื่อใช้สำหรับการร่วมมือในการผสมและวิเคราะห์ข้อมูล

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งานวิจัยนี้นำเสนอการออกแบบสถาปัตยกรรมของระบบความร่วมมือกันแบบกระจาย แนวความคิดของสถาปัตยกรรมระบบนี้คือการทำให้ข้อมูลข่าวสารสามารถถูกผสมและตีความร่วมกันระหว่างกลุ่มนักวิจัยผู้ซึ่งอาศัยอยู่กันคนละสถานที่ในเวลาจริง สถาปัตยกรรมถูกออกแบบบนพื้นฐานของเทคโนโลยีวัตถุแบบกระจาย COM/DCOM ซึ่งใช้สำหรับทำการแลกเปลี่ยนและกระจายข้อมูลระหว่างเครื่องลูกและเครื่องแม่บนเครือข่าย ในการออกแบบ ทุกๆอย่างในระบบถูกมองเป็นวัตถุ วัตถุแต่ละตัวสามารถติดต่อสื่อสารและส่งผ่านข้อมูล กับวัตถุอื่นๆในระบบได้โดยผ่านจุดเชื่อมต่อ เราได้ทำการสร้างห้องแล็บวิจัยแบบเสมือนสำหรับระบบความร่วมมือกันตามสถาปัตยกรรมที่นำเสนอ โปรแกรมต้นแบบอนุญาตให้นักวิจัยจำนวนมากสามารถร่วมมือกันทำงานได้ผ่าน web-browser โดยใช้ชุดของ เครื่องมือเช่น โปรแกรมการพูดคุย, whiteboard, การแลกเปลี่ยน audio/video, การโอนย้ายไฟล์ และโปรแกรมการแบ่งปันการใช้ซอฟท์แวร์ร่วมกัน ท้ายที่สุดเราได้ทำการวิเคราะห์ประสิทธิภาพการใช้งานของระบบโดยการทดลองใช้ห้องแล็บในการทำวิจัยร่วมระหว่างนักวิจัย 2 กลุ่มที่อยู่คนละสถานที่ในงานทางด้านการผสมและวิเคราะห์ข้อมูลภาพ ซึ่งผลการวิจัยได้นำเสนออัลกอริทึ่มแบบขนานใหม่สำหรับการผสมและปรับเพิ่มความชัดเจนของภาพถ่ายดาวเทียม อัลกอริทึ่มดังกล่าวสามารถที่จะถูกนำมาพัฒนาต่อเพื่อเป็นประโยชน์กับงานวิจัยทางด้าน remote sensing ในอนาคตต่อไป

คำหลัก : ระบบความร่วมมือกันแบบกระจาย, ห้องทดลอง/ห้องเรียนแบบเสมือน, การประมวลผลแบบขนาน, การผสมข้อมูลภาพ

ABSTRACT

Project Code : TRG4580104

Project Title : A Collaborative Environment for Distributed Data Analysis and Fusion

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This research proposes the design framework of a distributed, real-time collaborative architecture. The architecture concept allows information to be fused, disseminated, and interpreted collaboratively among researchers who live across continents in real time. The architecture is designed based on the distributed object technology, DCOM. In our framework, every module can be viewed as an object. Each of these objects communicates and passes data with one another via a set of interfaces and connection points. We constructed the virtual laboratory based on the proposed architecture. The laboratory allows multiple analysts to collaboratively work through a standard web-browser using a set of tools, namely, chat, whiteboard, audio/video exchange, file transfer and application sharing. Finally, the virtual laboratory technology demonstration was performed via a collaborative research among researchers who live in different countries. The virtual laboratory was proved to be effective and the research shows a promising parallel algorithm for image fusion and enhancement. The algorithm can be further developed to serve the research in the field of remote sensing in the near future.

Keywords: Collaborative Environment, Virtual Laboratory/Classroom Parallel and Distributed Computing, Image Fusion

เนื้อหางานวิจัย

1. Introduction (บทนำ)

This research aims at developing collaborative data fusion and analysis technologies based on the concept of Computer supported cooperative work (CSCW) [Churchill et.al. 2001]. The concept is used to create a computer-based, distributed, virtual workplace, where researchers can meet and interact with one another via the virtual agents or objects. Our work focuses on putting interactive, dynamic representations of data and people into virtual landscapes and offers powerful mechanisms for navigation, exploration and communication. These technologies have a wide variety of applications that range from data fusion, education, virtual shopping, architecture, virtualization, telemedicine, psychotherapy, games, flight simulators and military.

In today's world, where data analysis often requires a joint effort across the globe, communication and collaboration become crucial. A good data analysis technique alone is no longer enough. The technologies must be developed that allow information to be fused and disseminated, in real-time, to multiple observers and controllers. These technologies must provide a collaborative problem-solving medium with the ability to sense, interpret, and analyze data. Our research presents a design framework and implementation details of a virtual research laboratory. The goal is to facilitate a joint effort among dispersed researchers in data fusion and analysis.

Processing facility can be centralized while computing results are distributed. Our virtual laboratory is a solution for building a bridge for accessing, transferring and manipulating data/objects via the Internet. The implementation is done based on the concepts of "objects". Every component in the system is an object with a set of interfaces, which are defined based on functionality it provides. The system consists of several types of objects, namely, the security officer, the broadcaster, the listener, the client, and the communication channel objects. These objects are used to facilitate the sharing of information and applications. The real-time, collaborative research session can be created and shared among a group of participants, where each participant can gain an access to a session over the Internet. Figure 1 shows the general architecture of the virtual laboratory.

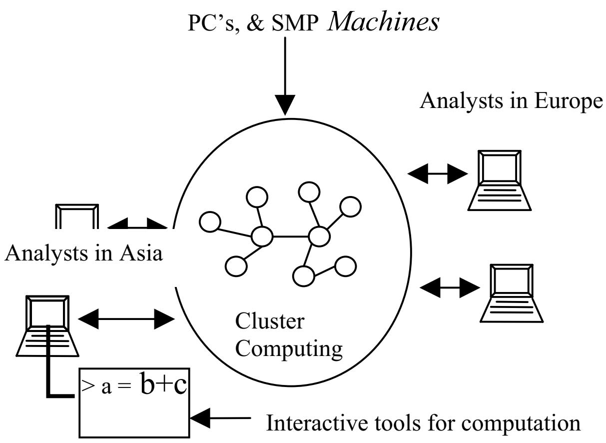

Figure 1.Collaborative Environment

A designated analyst (the first connection made to the system) controls access to a concurrent computation. Multiple analysts may subsequently connect to a computation from remote computers and are provided with read access to the computation. Coordination and discussion between analysts are carried through a chat-like sessions. The designated analyst is provided with the privilege to control the interaction modes and computation. The privilege can be handed off to other participants as needed. The same view of computation is available to all the analysts. Each analyst is able to manipulate data through a set of tools and share results. The tools provided will include, basic Linear Algebra, image processing, and data fusion.

In order to determine whether our virtual laboratory design has captured the objectives and is suitable for the tasks of remote research collaboration, we design an environment for collaborative research in remote sensing and data fusion areas. Data fusion for remote sensing requires the knowledge from multiple disciplines, namely, image fusion, remote sensing, concurrent programming, and mathematics. A collaborative effort was then put together between a scientist in the department of computer science and engineering, Korea University, Korea, and a group of engineers from King Mongkut's University of Technology Thonburi and King Mongkut's Institute of Technology Ladkrabang, Thailand. The preliminary goal was to establish an approach to the fusion of multi-spectral image for satellite image analysis. The algorithm was designed to enhance the spatial resolution of a multi-spectral image and to represent the embedded information with a minimum number of images. To increase the computing efficiency to the point where a real-time analysis is possible, the concurrent programming approach has also been considered. The result of the collaborative work via our virtual laboratory was reported in [Srinilta, Park, and Achalakul 2003].

With the promising fusion results from our initial work, we were encouraged to further explore the collaborative data fusion and analysis technologies, which are often used for information extraction. Data fusion refers to the combinational process of information from different sources into one representational format. Equipping the virtual laboratory with the ability to perform information extraction and fusion can facilitate research and development in the industries, as well as in academics.

Our value-added research to the virtual laboratory has been focusing on the fusion of image information. We use the term image fusion to denote a process of generating a single resulting image which contains a detail description of the scene from a set of source images. Images can be collected at different wavelengths, where each contains different information. The fused image should contain most if not all important information presented in the scene, and thus, useful for human and machine perception. For large image sets, such as those used in remote sensing, the overwhelming amount of embedded data makes it extremely difficult for researchers to perform a data analysis. In order to alleviate the problem, we develop an automated technique that fused the data together. Our fusion technique can be used to enhance data in a variety of applications in the environment planning including land use classification. Data fusion can increase the effectiveness of the environment impact assessment that would require the process of remote sensing data analysis. The major advantage of the technique is that it allows the image analysts to increase resolution in any dimension (spectral or spatial) without having to sacrifice the fine resolution or spectral integrity.

Many image fusion processing and analysis techniques in recent literature [Hall 1997] make use of the information that contain in the coefficient of the transformed domain. This paper proposes a parallel wavelet-based technique for multi-spectral image fusion. A multi-spectral image is a set of images of the same scene, which are taken at different wavelength. The fusion concept allows us to take advantage of fundamental characteristics of images from different wavelength and produce the new image which contains the most of the important information analyzes from original image set. The wavelet-based image fusion involves transformation of each source image from the spatial domain to spatial-frequency domains using the wavelet transform. The composite representation is then constructed using a wide variety of fusion rules, and the final fused image can be obtained by taking an inverse transformation. In the case of fusing images from two different sensors, the algorithm will enhance one sensor image using edge detail to match another. Wavelet-based methods are used in image fusion and analysis because the methods produce multi-scale images in the transformed domain, which provide information on the sharp construct changes as well as information in both spatial and frequency localization. A multi-scale representation is also useful for detecting different components in an image using different entropy.

There are two major contributions in our research plan: designing and developing a general architecture and a tool set that will allow a distributed and collaborative data analysis process, designing and developing a concurrent algorithm for data fusion and analysis for remote sensing applications. We have achieved the expected results in both contribution areas. A general architecture and a working prototype for a collaborative environment have been developed as reported in [Achalakul et.al. 2004 (a), Nuttaworakul and Achalakul 2002]. A concurrent algorithm for wavelet-based data fusion has also been designed as reported in [Achalakul et.al. 2004 (b)[1], Wiyarat and Achalakul 2004]. The application in remote sensing using multi-spectral imaging was used as our technology demonstration.

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[1] The manuscript is under the reviewing process

2. Research Methodology (วิธีทดลอง)

With the rapid growth of geographically dispersed research communities, many researchers in the CSCW area have focused their effort in designing the system, the network and the software architecture for the collaborative and real-time environment [Beca et.al. 1999, Flores et.al. 1999, Foster et.al. 1996].

A study by Ho [Ho et.al. 2000, Schraefel et.al. 2000] reported the work that facilitates the research collaboration between universities and industries. The collaborative infrastructures included mechanisms for supporting the virtual workplace, such as, adding members, controlling access, maintaining a discussion space and managing the shared document. Foster [Foster et.al. 1996] outlined the important trends in the development of a collaborative system based on distributed computing concepts, which have changed the basic of computing from desktop-centric to network-centric. He also identified a set of fundamental mechanisms that are needed for complex computational environments, namely, communication, configuration, discovery, naming, navigation, persistence, resource brokering, security and sharing. Chen [Chen et.al. 1992] defined the main features of distributed collaborative environment to be the collaboration management and the connection management. The task of the collaboration management is to create behavioral specifications of collaborations, to translate the specifications into a set of operational attributes and constraints as well as to instantiate the collaboration. The connection management task deals with the progress in instantiating the environment. Aoki [Aoki 2001] described the work in building collaborative environments for supporting web users on a real-time browser. The work has adopted a proxy-based approach, where normal web browsers are supported without any modifications or plug-ins. Java applets are used to provide communication capabilities. Collaborative functions are implemented in JavaScript by using the dynamic HTML functions.

Sinn [Sinn 1997] introduced the basic architecture for the heterogeneous distributed object technology. In this work, each computing involves a server, a client, an interface, and a network object. A network and an interface objects provide abstract layers to allow users to access and process data in a heterogeneous system using the same interface. Beca [Beca et.al. 1999] demonstrated how the distributed object technology could be efficiently applied to the process of building a collaborative application on the Internet. In their study, Tango beans components are used to develop collaborative tools and applications for synchronous distance learning and web conferencing. Tango Beans is a set of components based on the Tango Interactive framework that has been implemented to facilitate the rapid development of the collaborative applications. Tango Beans provides a high level interface to the collaborative services offered by the Tango Interactive framework. The technology consists of two components: TangoBean and ObjectPipe. Their main goal is to enable an easy creation of the collaborative applications for the Tango Interactive environment using visual programming tools. An application constructed using Tango Beans can communicate with other applications started in the same collaborative session. It can also access session information. Tango Beans are based on Java Beans-software component model, which allows a quick development of sophisticated tools through visual programming methods. However, Tango Beans has a limitation that the technology can only be used with Java applets and applications. In other words, applications developed using other languages cannot utilize Tango Beans collaborative components.

2.1 The design framework

In this research, we proposed a design framework that adopted the component architecture concept defined previously while focusing on the integration and the leveraging of the existing tools. The COM/DCOM standard [Grimes 1997] has been selected in our design because of its compatibility with most languages. Moreover, COM/DCOM allows us to take advantage of the Microsoft technologies, such as the plotting and the presentation tools, and thus, reduces the development time and cost. Our framework allows the researchers to communicate in real time. The researchers are able to exchange voice, video, text, and images, and to carry out the technical discussions. The experimental results can be shared and the computation can be collaboratively observed.

The basic design is to view everything as component objects: PCs, SMPs, a collection of analysis techniques, and interactive tools. An application can propagate its events to another application operated by another session participants, whereby the events are forwarded to appropriate components. This model allows actions in one application to be a mirror image of another. Another useful feature in the component model is the ability to transfer arbitrary data among applications. For example, a drawing created inside the virtual laboratory can be transferred to all participants who logged on at the latter time.

In respect to the idea described above we adopted Microsoft component model, COM/DCOM. COM represents all components reside in different platforms and DCOM is a mechanism defined to support communication across platforms. When a client process tries to communicate with a server process, COM will format the data getting it ready for remote sharing. Then, DCOM facilitates the interaction through Object Remote Procedure Call (ORPC). COM/DCOM is a mechanism that can work well with Internet-based applications because it can work natively over the HTTP protocol and firewalls. In other words, a COM component will be able to go through the firewall just like a HTTP object, and thus, allows a smooth integration of the client-side components to the collaborative architecture [Lambert et.al. 1997]. In addition, DCOM is a Microsoft object model that has been mostly implemented. It is relatively robust, and easy to maintain and extend.

To demonstrate the capability of our virtual laboratory, we perform a distributed-collaborative research on the environment. The computing platform provides the raw computational resources for any concurrent algorithms or analysis techniques. The centralized resources are used to compute and to create a series of analysis results. Multiple analysts can, then, connect to the system to view the results using standard web-browsers. In other words, the collected results can be processed and distributed for collaborative research over the Internet. To allow the sharing of these results residing in the centralized computing units, The DCOM standard is employed as shown in Figure 2. The server component consists of a computing object, a security officer, a broadcaster, and a listener. The client components can instantiate collaboration by communicating with the caller objects. The caller object can, then, sends a client call to the server through DCOM. All client requests are sent to the listener, a mechanism used for monitoring calls. The listener communicates with the security officer to verify the client's access right, which is kept in the database object. If the access is granted, the new session is started. The clients can then work collaboratively via several applications: chat, whiteboard, audio, video, file transfer and application sharing. Using the Channel Object, the applications and the analysis results can be shared and researchers can edit contents collaboratively. When the channel object is called, the broadcaster sends the shared data to the requested clients. All the intra- and inter-component communications are done through DCOM layer and the Internet is used as a main communication medium.

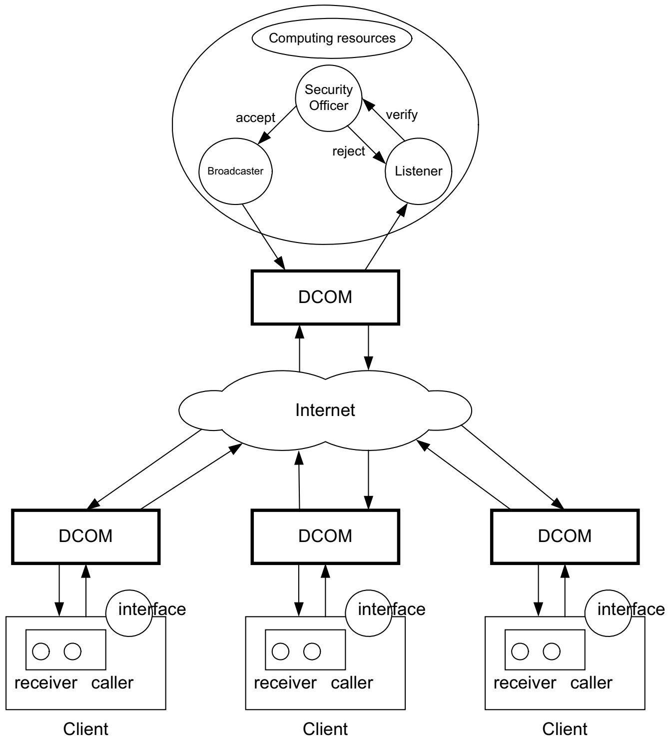


Figure 2. DCOM for Virtual Laboratory

To support this architecture, a collection of collaborative tools is proposed. We leverage several existing technologies to create tools that integrate collaboration features into our system. NetMeeting Software Development Kit (SDK) [Suresh et.al. 2002] is employed as the core technology.

2.2 The implementation detail

The implementation of our virtual laboratory is done based on the concepts of "objects". Every component in the system is an object with a set of interfaces, which are defined based on functionality it provides. The system object hierarchy is illustrated in Figure 3. Each object communicates and passes data with other objects in the hierarchy by a set of interfaces. The object instance manager is implemented to manage the object's interface pointer. Its job is to create a connection to the sink and to pass calls to each object's interface.

From Figure 3, the client joins a collaborative session by communicating with the caller object. The caller object sends the client calls to the listener. The listener forwards the calls to the security officer object, whose job is to verify an access right with the database object. Only the authenticated clients can gain an access to the channel objects in the system. The channel object provides services such as data transfer and application sharing. The broadcaster object is then invoked. This object opens the link to the channel object and thus, allows the client to see the broadcast information in the current session. The detail functionalities of each object can be described as follows:

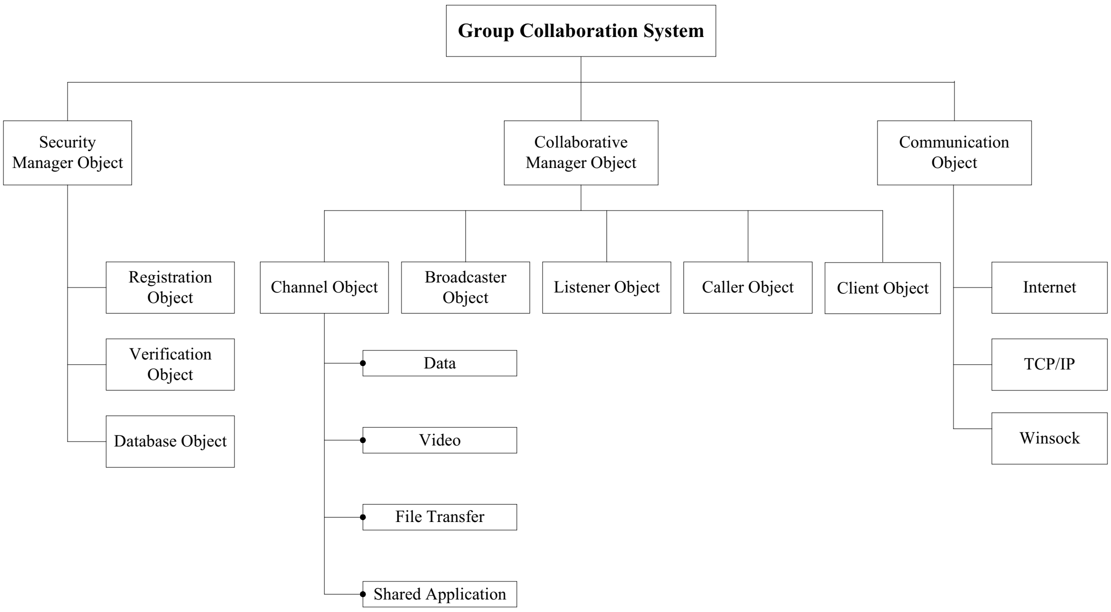


Figure 3. System Objects Hierarchy

The security manager object maintains the member lists of the system. It monitors whether each user's request should be authorized. This object also handles the registration for new users and maintains the users' database. The following pseudo code shows how the security object works.

Activate Database object

Case: member login

Get Username and Password

If valid user then

Accept calls

Connect to the collaborative manager object

else

Reject calls

End if

Case: new user registration

Get net user information

Save to database

The collaboration manager object is the main component that conducts the collaboration sessions in a virtual laboratory. The collaboration manager is responsible for initializing and managing the collaborative sessions. It also manages incoming and outgoing calls, controls data distribution among all session participants, and manages local computing resources. The collaboration manager tasks can be listed in the following pseudo code.

```
Begin
    Accept a session request
    Get environment information
    Initialize the system variables
    Create a collaboration session
    While (not terminate)
        If call request
            Service call
        Lists all calls in progress
    End while
End
```

The caller object is a mechanism used to control the incoming and the outgoing calls to the collaboration session. The caller has two major functionalities: Call Enumerator and Call Notification. The call enumerator object lists active calls in a collaborative session, while the call notification object handles information about the incoming and the outgoing calls during group participation, which allows the designated participant to accept, reject, and cancel new calls.

```
Begin
    While(not terminate)
        If (incoming call)
            [state, name, address] = GetCallInformation()
```

```
                        user = GetUserData()
                        if (accepting call)
                                call security officer object
                        else
                                cancel call
                end if
        end while
End
```

The client object provides the interfaces to members of a collaboration session. The interfaces include methods, such as information retrieval, which is used to retrieve member identifier, name, address and shared state.

The channel object allows each participant to share resources, such as custom applications, data, file, video and audio. It provides a set of interfaces, which can be used to manage communication in all channel types. The channel object will be called whenever a channel is to be added, removed, or updated. A pointer to a new channel is sent as a parameter to the collaboration manager for all session members to use. The manager will respond to the notification based on the type of the channel. The following pseudo code shows how channel interface works.

```
Begin
        While (not terminate)
                Case add: getChannelType
                        CreateChannel
                        ActivateChannel
                        List = getSessionParticipantList
                        AddParticipant(List)
                Case remove: List = getSessionParticipantList
                                NotifyParticipant(List)
                                RemoveParticipant(List)
                                RemoveChannel
                Case update:    If (channel active)
```

getChannelType

List = getSessionParticipantList

UpdateChannel

NotifyParticipant(List)

End if

End while

End

The Channel object in our system can be divided into four types: the data channel, the video channel, the file transfer channel and the shared application channel objects. The data channel object provides methods for data sending and receiving among all participants. This object controls and interleaves all data exchanges for chat and whiteboard applications. The video channel object manages the exchange of the video data. The object mainly handles video conferencing applications. The file transfer channel object manages the file exchange by providing supports for sending and receiving different type of files similar to the FTP application. The shared application channel object allows participants to share any custom application during run time. All participants can view the same data and actions as the program progresses; for example, the researchers can collaboratively provide the input and monitor the results of a computation. This channel object provides methods to allow the designated client to set the level of control that each participant has on a shared application. There are two types of messages circulated among the participant list in this channel object: State change and member change. The state change message is used to notify all participants in the list whether the current application is being shared. The member change message indicates the changes in participant list (add, remove, update).

The broadcaster object handle information broadcast. The communication mechanism can be described in Figure 4.

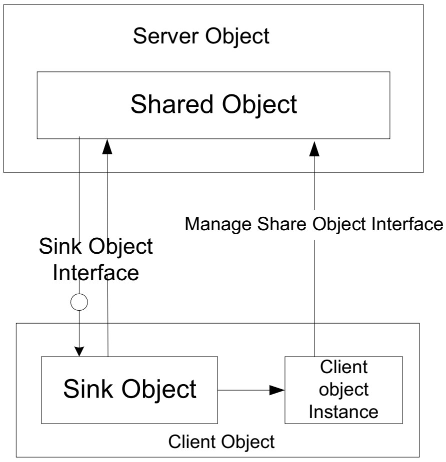


Figure 4. The Broadcasting Mechanism

Each client has two components, which are the sink object and the client object instance. The client object instance is used to manage actions on share objects. Any action applied on the shared object is forwarded to the server side, in order for the action to be recorded and broadcasted. The sink object is connected to a communication point, which is used to echo interactive mouse-motion events across the network. All the events are first sent to the server object and then are broadcasted to the clients in the session.

The communication object handles the low-level socket communication. The NetMeeting communication technology is leveraged in our system. The transmitting protocols available in this object include TCP/IP for data transmission and UDP for audio and video transmission.

3. Experimental Result: The System Evaluation (ผลการทดลอง: การใช้งานระบบ)

Quality evaluation is performed on the virtual laboratory to determine whether our design has captured the objectives and is suitable for the tasks of remote research collaboration. During this evaluation process, the system usability is measured. System usability is defined in ISO 9241 draft standard as the “extend to which a product can be used with effectiveness, efficiency and satisfaction in a specified context of used” [Fitzpatrick et.al. 1998]. In this section, we attempt to verify our system usability using the example application of a remote collaboration in satellite image fusion and analysis. This particular project required the knowledge from multiple disciplines, namely, image fusion, remote sensing, concurrent programming, and mathematics. A collaborative effort was then put together between a scientist in the department of computer science and engineering, Korea University, Korea, and a group of engineers from King Mongkut's University of Technology Thonburi and King Mongkut's Institute of Technology Ladkrabang, Thailand. The preliminary goal was to establish an approach to the fusion of multi-spectral image for satellite image analysis. The algorithm was designed to enhance the spatial resolution of a multi-spectral image and to represent the embedded information with a minimum number of images. To increase the computing efficiency to the point where a real-time analysis is possible, the concurrent programming approach has also been considered. The collaborative framework of the project can be depicted in Figure 5.

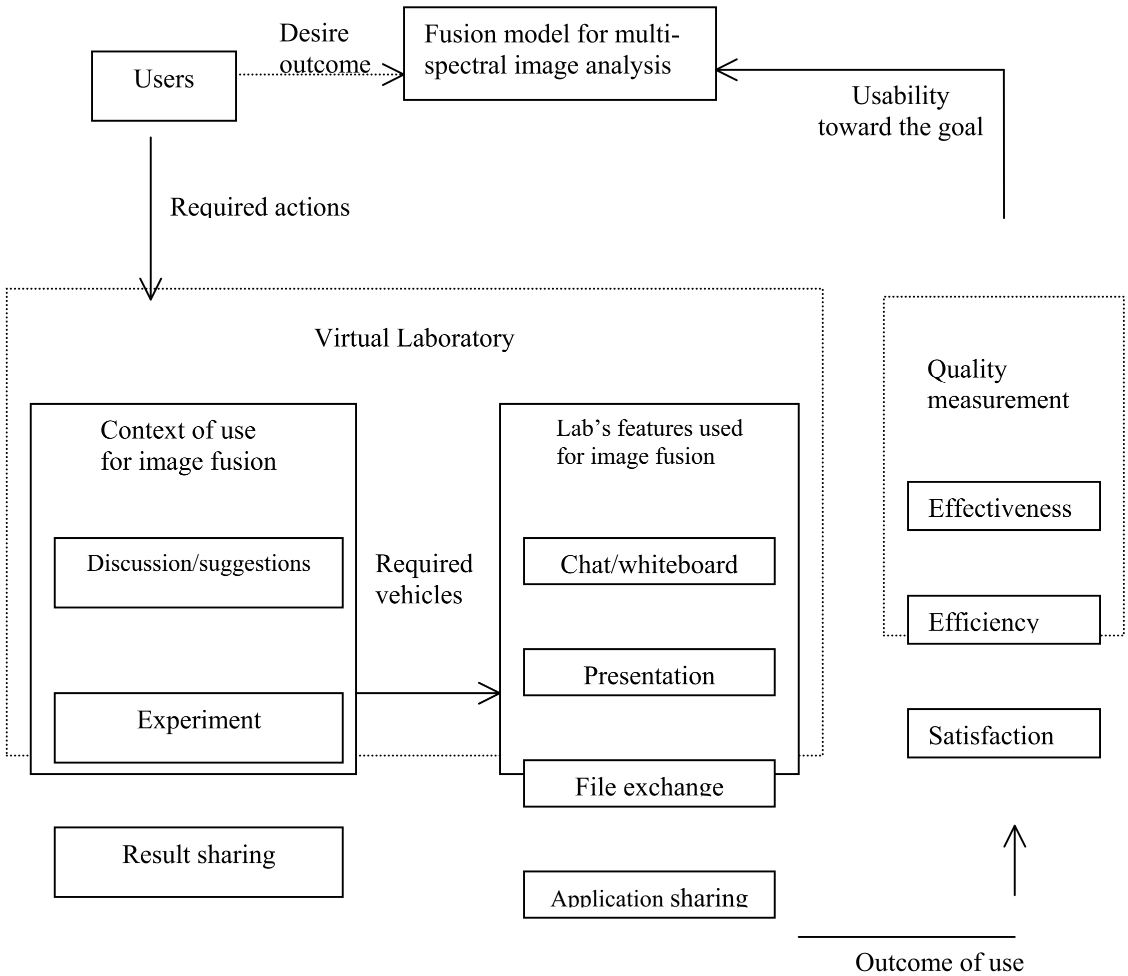


Figure 5. Collaborative Framework for Image Fusion Application.

The desire outcome is to establish an effective fusion model. With this objective in mind, we have designed the computer-based collaboration method on top of our virtual laboratory concept.

The virtual research community between multiple campuses was then, established. The custom web pages with the embedded Active X control components were developed to facilitate the information sharing. The community memberships were granted based on our security objects. The laboratory context of use for this multi-discipline project includes the model design discussion, the experiment observations, and the results sharing. Several tools provided in the virtual laboratory were used as vehicles toward this context of use as shown in Figure 5.

The first phase of the project was the remote discussion to develop the suitable fusion model. Several suggestions on signal processing techniques, such as wavelet transform, discrete cosine transform, and principal component transform have be traded via the chat, the whiteboard, and the presentation tools. The discussion was successfully carried out and the preliminary fusion models were exchanged via the file-transfer tool. The conclusion has been derived collaboratively to develop the fusion model based on the Principal Component Transform (PCT) [Jackson 1991]. A satellite multi-spectral image was the input to our fusion model. Eigenvalue was the feature of interest. The PCT-based model took the source image and computed the eigenvalues. With respect to these eigenvalues, the model then created a collection of images in the feature domain. Each created image was called the Principal Component. Due to the statistical properties of the PCT, the information embedded in each frame of the multi-spectral input image was pushed toward the front principal components.

After the fusion model was developed, several experiments have been observed remotely in real-time through the application broadcast mechanisms. Mathlab was used as the main tool. The researchers exchanged the ideas through the shared screen of Mathlab. Chat tool was also used, in parallel, to carry out the discussion. The experimental data (image and text files) were transferred on a regular basis. The interactive experiments were performed on a set of compressed and scaled-down images (size of less than 200 Kbytes/image) for convenient in transferring. However, the full size images (70 Mbytes/image uncompressed) were used to produce the final result. The fusion algorithm and the results were cooperatively analyzed based on the statistical properties of the PCT. Microsoft Excel was used primarily in this phase.

The experimental results show that more than 98% of the information, embedded in the satellite image set, is pushed into the first principal component. There is almost no significant variance left in the latter components. The conclusion can, thus, be made that our fusion model successfully summarizes the spectral information from the multi-spectral satellite scene and presents it in the few resulting images. These images offer a significantly improved contrast and details compare to the original scene, and can later be used by the scientist in land use classification applications. The experiment observation also suggested the need for the concurrent programming technique to be adopted to enhance the computing speed. The concurrent algorithm was then collaboratively designed. This fusion research project was successfully carried out entirely in the virtual laboratory, presenting a major cut-down on time and expense spending on campus visits. The details of the project are reported in [Srinilta et.al. 2003].

During the course of this research collaboration, the outcome of use for the virtual laboratory was recorded in terms of effectiveness, efficiency, and satisfaction. The Heuristic evaluation [Avouris et.al. 2001] was applied by using questionnaires on a group of 10 evaluators involving in the project. The evaluators are researchers, engineering students and faculties, and a project administrative person. This group of people has a wide variety of computer skill, ranging from beginner to expert. However, the majority were expert users. The evaluation sheet was used to quantify the judgment on each category of quality measurement presented in Figure 5. The system effectiveness was measured upon the percentage of communication goal achieved and the percentage of success in completing the tasks in each phase of the project. Questions asked involved around the effectiveness and the convenience in using the tools, carrying out the discussion and sharing the data of different types. The efficiency was measured on the time and the cost of completing the task in the virtual laboratory against the use of the traditional means. The satisfactory level was measured using questions related to rating scale and frequency of errors and complaints. The questionnaires also included the questions about the overall judgment on the system functionality, maintainability, and flexibility. The questions in this category emphasized on the ease of use, the feature availability, and the system presentations. The subjective judgments on the system were quantified by assigning points between 1 and 5 for each question in each category. The quantitative evaluation was then calculated by the formula $e = \sum r_i$, where r_i was the average score of questions in each category. With the highest score being 5, the result of the survey is presented in the following table.

	Effectiveness	Efficiency	Satisfactory	Overall Judgment
Average values	3.33	4.01	2.9	3.4

Given all categories an equal weighting factor, the overall usability of the virtual laboratory is measured at 68 %, which is satisfactory for this beta version. The efficiency rating received the highest score at 4.01. This number reflects the good improvement in terms of time and cost for collaborative research in the virtual laboratory compare to other traditional ways. While the efficiency was rated high, the satisfactory level was below our expectation with the score of 2.9. Based on the oral suggestions made during the evaluation process, the low level of satisfaction causes by the lack of customized graphical user interface (GUI), and offline messaging services. The GUI and Online help improvement were also recommended. These suggestions have been taken into consideration for our next release. It was also noted that the video feature introduced a low frame rate and poor quality, which made video conferencing inconvenient. However, it is hard to overcome this problem due to the use of the Internet and the network speed on campus. The Internet is a best-effort service and does not offer any quality of service guarantees. Loss of data packets during transmission is likely to happen, which causes the most trouble for real-time video. Moreover, the network technology provided on the King Mongkut's University of Technology Thonburi campus allows the maximum speed of 18 Mbit/sec, which was the bottleneck in video transmission. The effectiveness rating of 3.33 was acceptable for our initial system. Several improvement including video/voice transfer rate, and concurrent collaborative sessions were being incorporated to raise the effectiveness level. With the limited graphical user interface and online help features, the overall judgment rating of 3.4 was above our expectation.

In conclusion, the evaluation process presents a good effectiveness, efficiency and overall judgment values, which implied that our virtual laboratory is suitable for use in remote research collaboration. The features available in the system have answered the needs of real users carrying out real tasks in real research environment.

4. Technology Demonstration in Remote Sensing

The work on the PCT-based image fusion algorithm [Srinilta et.al. 2003] presented in the previous section was carried out on the virtual laboratory environment. This initial work was performed as a proof of concept for our laboratory design. However, the collaborative research displayed a good potential in remote sensing. Thus, we decided to pursue our work in the image fusion area. The objectives of this second part of the work, apart from being a technology demonstration[2], was to achieve an algorithm that would be beneficial to other environmental research in land use classification applications. The achieved algorithm can also be built in as a tool in our virtual laboratory in the future. The summary of our findings in the fusion research is reported in the rest of this section.

4.1 Wavelet-based image fusion

Multi-spectral image fusion is the process of combining images from different wavelengths to produce a unified image, removing the need for frame by frame evaluation to extract important information. Image fusion can be accomplished using a wide variety of techniques that include pixel, feature, and decision level algorithms [Hall 1997]. At the pixel level, raw pixels can be fused using image arithmetic, band-ratio methods [Richards and Jia 1998], wavelet transforms [Li et al. 1995)], maximum contrast selection techniques [Peli et al. 1999], and/or the principal/independent component transforms [Gonzalez and Woods 1993, Lee 1998]. At the feature level, raw images can be transformed into a representation of objects, such as image segments, shapes, or object orientations [Hall 1997]. Finally, at the decision level, images can be processed individually and an identity declaration is used to fuse the results [Hall 1997]. Many image fusion techniques in recent literatures often utilize the multiscale-decomposition-based methods. The methods generally involve transformation of each source image from the spatial domain to other domains, such as frequency or spatial-frequency domains. The composite representation is then constructed using a wide variety of fusion rules, and the final fused image can be obtained by taking an inverse transformation. Several multi-scale transform provide both spatial and frequency domain localization. However, we chose to study the wavelet transform as

[2] The process of the fusion algorithm design and development was not entirely performed in the virtual laboratory

it provides a more compact representation, separates spatial orientation in different bands, and efficiently de-correlates interesting attributes in the original image.

Our fusion algorithm is based on a variation of the Daubechies's discrete wavelet transform [Press. et al. 1995] and the implementation of the maximum coefficient fusion system. From the experiments, we found that the DWT introduced a relatively complete set of embedded information with little noise and also relatively efficient in computing. The wavelet theory is used as a mathematical foundation to produce coefficient components for each source image. Then, a composite representation is constructed, based on the maximum absolute coefficient selection. The model is capable of joining the composite discrete wavelet, supporting the sharpness and brightness changes, edges and lines boundaries or even feature in the image set. In our approach, the coefficients are associated with one another in the same scale, which can be called a single-scale grouping scheme. The fusion algorithm can be described in figure 6.

The 2-level decomposition of Mallat's Algorithm for DWT is utilized in our work. The DWT is applied recursively over the spatial data. Each input image will be decomposed and down-sampled using the low pass and high pass digital FIR filters. The FIR filters construct a set of approximation coefficient and three sets of detail coefficients (horizontal, vertical, and diagonal), which provide the detail of image information at different scales. First, the row of the input image is convolved, and the column is then down-sampled to obtain two sub-images whose horizontal resolutions are reduced by a factor of 2. The advantage of down-sampling is reducing image size, while maintaining the embedded information. Both sub-images are then filtered and down-sampled into four output images producing high-high, high-low, low-high, and low-low bands.

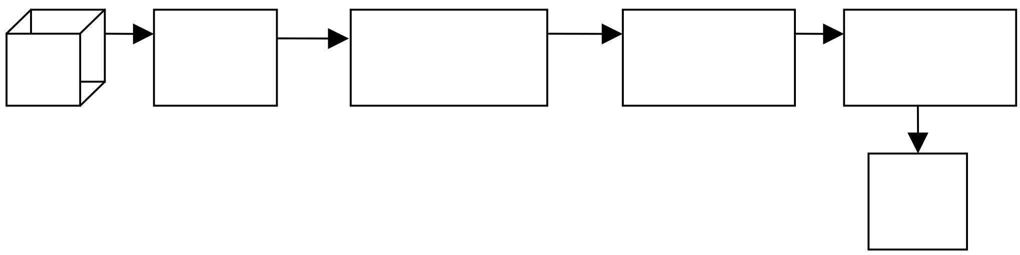


Figure 6. The fusion algorithm

The activity level is then measured. The level reflects the energy in the space between the coefficients. Our work employed the coefficient-based activity (CBA). The technique considers each coefficient separately. After the decomposition process, we obtain a set of coefficients in several decomposition levels. We, then, experimented with the single-scale grouping method [Zhang and Blum 1999], which joining the coefficients from the same decomposition scale.

After achieving the approximate coefficients and the group of detail coefficients, we create the resulting image by fusing multiple components using the maximum selection rule. Let I_n be the coefficient matrix that represents the original image of frame *n*. I^h_n represents the high frequency components, and I^l_n represents the low frequency components. G_n denotes the gradient of the high frequency component I^h_n., G_n = $gradient(I^h_n)$. The fused coefficient of all high frequency components, F_h, can be calculated as shown in the following code fragment.

```
max = 0
for ( i = 0; i < n ; i++)
        if (Gmax < Gi)
                max = i ;
Fh  =  I^h max
```

The fused coefficient of all low frequency components, F_l, can be calculated as follows: F_l = max (I^l_n). Using the fused components of the low and the high frequency coefficients, the resulting image can then be generated by taking the inverse transform of both fused components.

Section 4.1 presented the summary of our fusion model. The details can be found in [Achalakul et.al. 2004 (b)]

The wavelet transform has high computational costs because it involves pixel convolution. The performance requirement discourages the use of our algorithm in real-time applications. To improve performance, we explored a concurrent algorithm employing low-cost, commercial-off-the-shelf computers connected using a standard LAN.

4.2 The concurrent fusion algorithm

The concurrent algorithm decomposes each image frame into sub-images, which can be operated on relatively independently. Each sub-image consists of a set of pixels. The allocation of sub-images to processors is managed through a variant of the manager/worker technique depicted in Figure 7 [Chandy and Taylor 1992]. This strategy employs a manager thread that performs the above decomposition, and distributes sub-cubes to a set of worker threads. Each worker performs relatively independent components of the overall image transformation. A manager thread coordinates the actions of the workers, gathers partial results from them, and assembles the final resulting image.

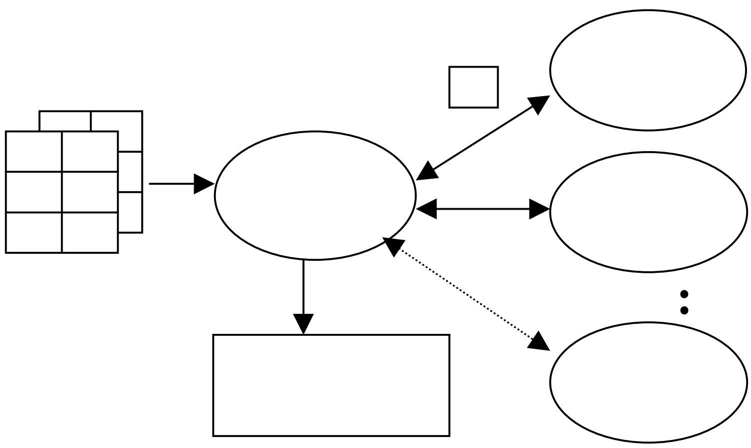


Figure 7. Manager-Worker Model

The main abstract code of the algorithm is shown in Program 1 and is executed at every processor on the network. The manager and workers are executed as independent threads with a single thread per processor. The manager abstract code is shown below in Program 2. The manager thread serves primarily to synchronize and accumulate partial results from the workers. The manager loads original image frames and then distributes them to a set of workers (line 4&5). It also synchronizes the calculation by making sure that the partial results are received from all workers before moving on to the next stage in the algorithm. When the partial results are returned (line 6), the manager applies the maximum selection rule (stated in the previous section) to form a fused coefficient set (line 7&8). The fused coefficient set is then divided into subsets (line 9) and the subsets are distributed once again to perform the inverse transformation (line 10&11). The final result is assembled after the all workers send back the partial results (line 12) and then is displayed (line 13).

```
main() {

    p = getMyProcessorId()

    if(p == 0) {

            numSubImages = getNumSubImages
```

Program. Main

```
worker(numSubImages, numWorkers) {
aSubImage = recv (manager)
coeffMatrix = convolve(aSubImage)
coeffMatrix = activityMeasure(coeffMatrix)
coeffMatrix = coeffGrouping(coeffMatrix)
send (manager, coeffMatrix)
subCoefficient = recv(manager)
subImage = inverseTransform(subCoefficient)
send (manager, subImage)
```

Program. Worker

```
manager(numSubImages, numWorkers) {

1  coefficientCube = [][]
2  coefficientFused = []
3  finalImage = []

4  foreach worker i {
5     send (i, aSubImage)

6     coefficientMatrix [i] = recv(i)
   }
7  coefficientCube =  build (coefficientMatrix [])

8  coefficientFused = maxSelection(coefficientCube)
9  subCoefficient = sizeof(coefficientFused) /
                    numWorkers

10 foreach worker i  {

11     send(i, aSubCoefficient)
12     finalImage = merge (finalImage, recv (i))
   }

13  display(finalImage)
```

Program. Manager

Each worker thread waits for the manager to send its part of image (line 1). Once the sub-image arrives, the convolution is performed to filter and to downsample the sub-image using Mallat's Algorithm (line 2). The activity level measurement and the coefficient single-scale grouping are then performed (line 3&4). The resulting coefficient matrix is sent back to the manager to be fused (line 5). The worker then waits for its next set of data (line 6). Once received, it applies the inverse wavelet transform to convert the coefficient set back to the spatial domain (line 7). The results are sent to the manager for displaying (line 8).

4.3 Image Evaluation

In our work, we use the SNR (signal-to-noise ratio) to evaluate the image quality. The method is widely used in remote sensing as quality measurement methods. Moreover, we also evaluate the image quality using human interpretation to assure that the measurement is not done only through the pixel differences. The signal-to-noise ratio (SNR) reflects the differences of the information content (referred to as errors) between an original image and a fused image using the average data. The SNR numbers are reported in Decibels (dB) as a measure of the relative weight between two images. A higher number in dB indicates a higher correlation. The SRS is directly proportional to the image quality.

$$SNR = 10\log\frac{\sum_i\sum_j (Bv_{orig(i,j)} - Bv_{fuse(i,j)})^2}{\sum_i\sum_j Bv_{orig(i,j)}}$$

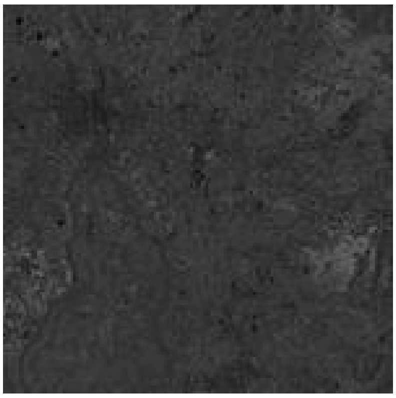
From the equation, i and j define the pixel coordinates, $Bv_{orig(i,j)}$ represents the pixel intensity (brightness) value of the original image, and $Bv_{fuse(i,j)}$ is the intensity of the fused image.

To demonstrate our parallel fusion model, it was applied to the Landsat Enhanced Thematic Mapper satellite data. The Landsat ETM+ sensor provides data from eight spectral bands ranges from 0.45 to 12.5 micron. The sensor is used to acquire images around the globe at discrete spectral resolution. The spatial resolutions of the data range from 15 to 60 meter, where the 30-meter resolution is for the visible and near-infrared (bands 1-5, 7). The thermal infrared (band 6) is 60 meters, and the panchromatic (band 8) is 15 meters. The approximate scene size is 183 x 170 kilometers (8900x8290 pixels). All of the multi-spectral images are arranged into a three-dimensional data structure of two spatial dimensions and one spectral dimension. The data set used in this work is radiometric-corrected images from path 131, row 47 with center of coordinate N18.79, E098.62. The acquisition date is 23 February 2002. The scene corresponds to the area in Chiang Mai, Thailand, which contains a good mixture of forest, river, road, and urban area. Figure 8 shows some example images of Landsat ETM+ data. From the original data, band 3 shows the road systems, band 5 emphasizes the river and the airport strip, while band 8 and band 5 have the best contrast for the urban area.

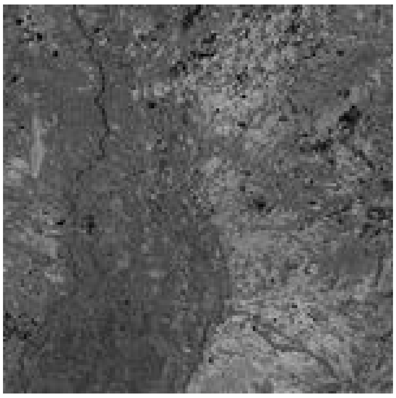
(a) band1

(b) band2

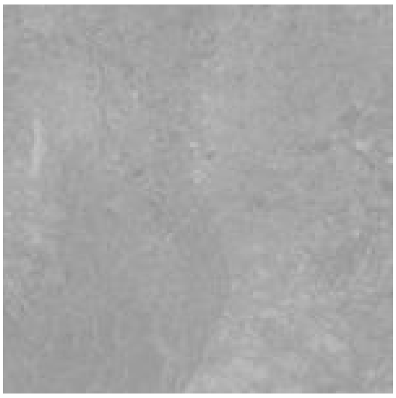
(c) band3



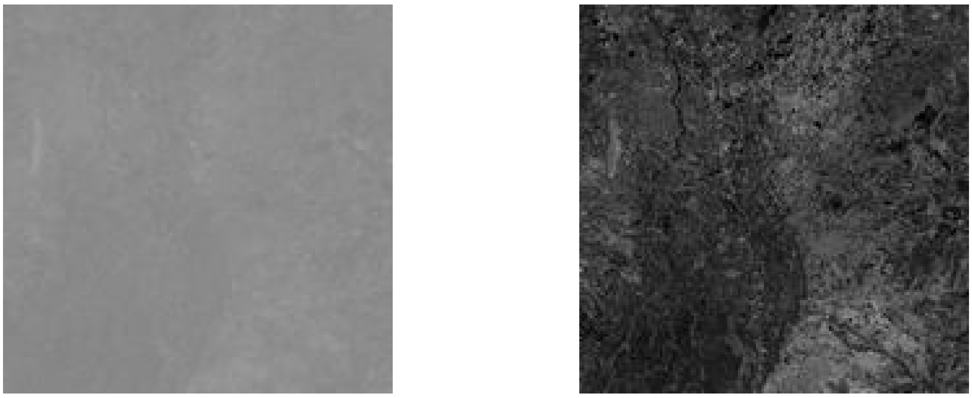
(d) band4



(e) band5



(f) band6



(g) band7 (h) band8

Figure 8. The Landsat-7/ETM of Chiang Mai, Thailand

The images in Figure 8 are used as an input to our parallel fusion system and the resulting image (fused image) is shown in Figure 9. The goal of the fusion system is to gather the most information and present it in a single image. From Figure 9, notice that the image quality, especially the contrast level and the image details are visibly enhanced compare to the original images. The result suggests that the fusion system is capable of summarizing most of the important information and put it into the resulting image. To quantify the image quality, we employed the signal-to-noise ratio (SNR) method [Zhang 1998]. The SNR value represents the level of information loss between the original image and the transformed and subsequently inverse-transformed image. The work by [Chardon 1999] suggested that the SNR values between 0-20 dB represent an unusable output image, 20-30 dB represent a poor quality image, 30-40 dB represent an image with snow and some detailed loss, 40-50 dB represent a good quality image with very little noise, and 50-60 dB represent an excellent image quality. From our experiment, the SNR of an output image relative to the original images can be shown in Figure 10. Notice that, in band 8th, the original image has a higher resolution than other bands as it is taken at a closer distance (15 meters). The frame also provides more resolution details.

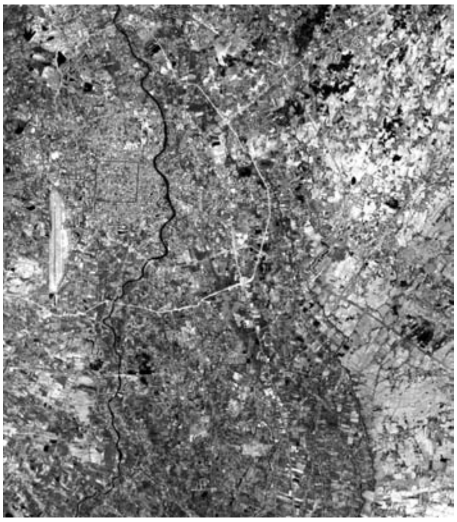


Figure 9. The resulting image

Thus, the SNR of the fuses image compare to this band is relatively low suggested that some information embedded in band 8th might be lost. However, at 39 dB, the detail loss is still considered low with minor amount of noises. The results from Figure 7 also suggest that the information embedded in the first seven bands is likely to be found in the fused image due to a very low level of information loss and little noise is presented. The SNR results, thus confirmed the visually contrast and detailed improvement in the resulting image.

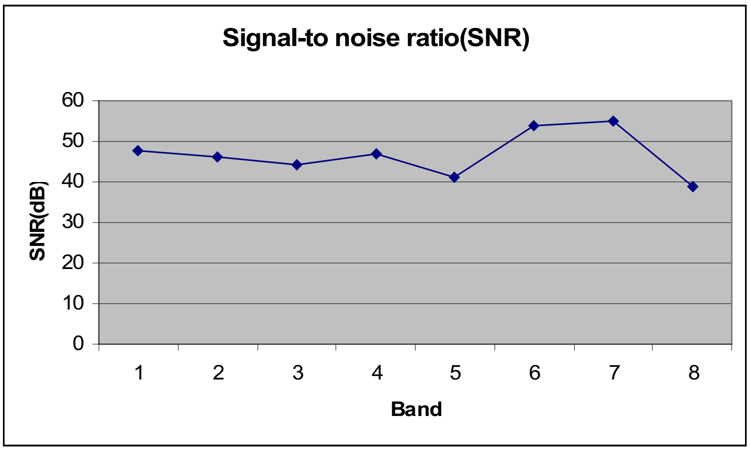


Figure 10. The SNR plots

The results from both image quality measurement methods and the visual interpretation offer the same conclusion that the fused image is a good representation of the original image set. The resulting image can, thus, be thought of as a summarized image of the original image set. This image can then be used to help researchers in classifying process of the land use applications, eliminating the need for a frame-by-frame evaluation.

4.4 Parallel Performance

We study the algorithms scaling properties to determine the effectiveness of the parallel algorithm. The performance when generating the results presented in the previous section were measured on a networked workstations of eight nodes. Each node is a Silicon Graphics O2 running at 300 MHz with a RAM of 128 MByte. Figure 11 shows the speed up gained as a function of the number of processors, plotted against the ideal speedup.

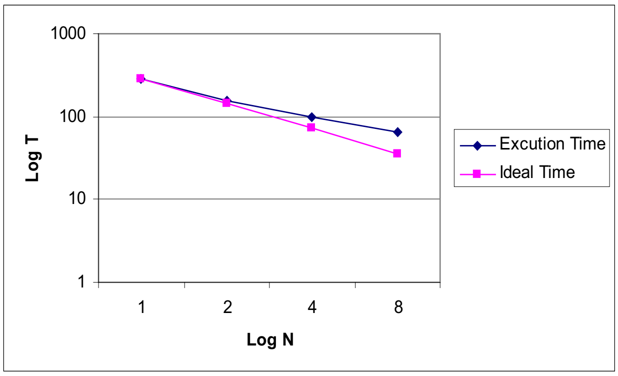


Figure 11. Performance

For the image size of 1000x1000 pixels, we found that the algorithm performs within 8% of linear speedup at 2 processors, 25 % at 4, and 40% at 8 processors. The performance drop increases with the number of processors. This speed degradation was dominated by the communication overhead in sending images back and forth between the manager and a set of workers. The synchronization overheads were present, although not significant. Note that coefficient fusion step of the algorithm that involved sequential code to computer the maximum selection rule is not a significant factor in overall performance. Hence, there was no extensive effort to optimize this step through parallel execution.

To reduce the communication overheads, the next version of the parallel code will add granularity as another variable. We suspect that by adjusting the granularity, we will be able to find the optimum grain size for the data set. Communication and computation overlapping concept can be utilized and thus reduce the effect of the overheads. Applying the dynamic load balancing should also help as the load can be transferred to faster processors introducing the best system utilization.

4.5 Fusion algorithm for land use classification

The derived land use and land cover information is important and widely applied for many planning, assessing and monitoring in environmental and natural resource management. The change of land use/cover inventory is crucial information for understanding the impact of changes on ecosystems, as well as for modeling the earth dynamics. Various remotely sensed imageries with the multi-resolution such as Landsat 7 ETM+ has become the source of information in both spatial and spectral domains in land use/cover classification process. Scientists depend on automate analysis algorithms as well as information derivation based on human visual system to classify land use. Thus, fused images with enhance spatial and spectral information can aid image interpretation process greatly [Shi et al., 2003].

The quality of satellite images is an important factor for the scientists to achieve an accuracy interpretation. In most applications, several basic image characteristics are considered: shape, size, pattern, tone, texture, shadow, and resolution. The parallel wavelet-based fusion model presented in the previous sections is one of the automated image processing techniques that can increase resolution in spectral and spatial context of Landsat 7 ETM+ imagery. The fused image is visibly enhanced and can be used along with the eight original images effectively for analyzing and monitoring the rapid environment changes. Applications that can benefit from the new information include geologic and soil mapping, agriculture (e.g. crop-type classification and management), forestry, rangeland, water resources, urban and regional planning, wildlife ecology, and environmental assessment.

Our experimental scene covers parts of Chiang Mai, the second largest of the seventy-six provinces, located in northern region of Thailand from latitude 17° 21' to 20° 10' N, and longitude 98° 40' to 99° 05' E. The wide range of ecological and local climate conditions in the area reflects the diversity of forest, which still covers more than 70 percent of the total area in the mountainous landscape. In the low land to gently sloping topography is under agriculture utilization. Most of the agricultural products are economic crops such as rice, soybeans, mungbeans, groundnuts, tobacco, shallot, garlic and other vegetables. Moreover, Chiang Mai urban areas (residential and commercial districts) are growing rapidly making the land use control a significant issue in the environmental research of Thailand [Taweesuk, 2001].

In order to monitor land use in Chiang Mai, a land cover map is created and is compared to the map of previous years. The dynamics of the land use can then be recorded. The map creation process is usually done either by visual interpretation or nearest neighborhood classification algorithm. The fused image from the algorithm presented in the previous sections, can increase the accuracy of the nearest neighborhood classification algorithm as the algorithm depend highly on the contrast and detail information in the image scene.

In visual interpretation process, the scientists manually digitize different areas in the image into different layers. For example, the water boundary might be identified as shown in figure 12.

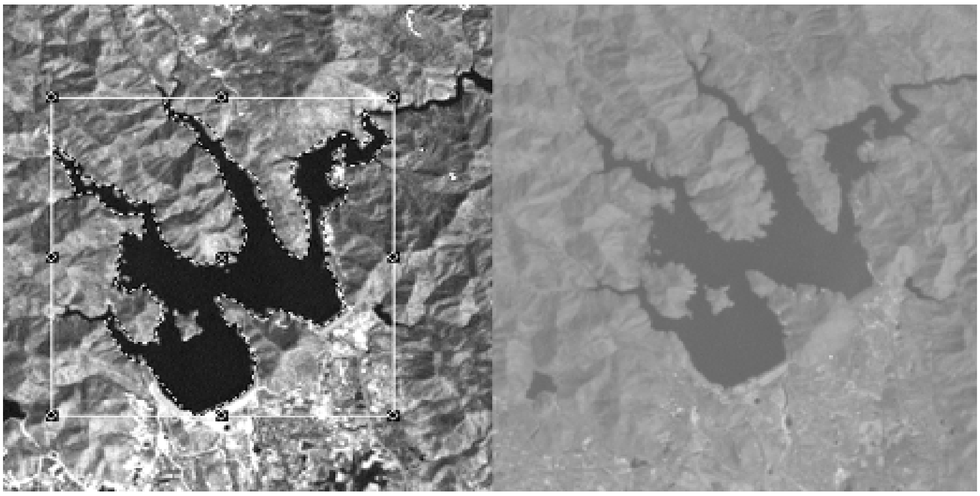


Figure 12. Digitizing of Water Boundary

Figure 12 shows the manual digitizing process. The image on the left is a zoomed area from our resulting fused image. The image on the right is the color image derived from the original Landsat images. It is clearly observed that the fused image provides more contrast and feature details needed for the boundary digitizing around the target feature. After the digitizing process, a new layer based on the line drawing is created and identified as water boundary. This new layer can then be color coded and imposed on the original image scene to identify various discrete land cover in the study area. The statistical analysis such as, percentage of water boundary compare other land use/land cover classification can also be derived. Various types of land use will be grouped into different levels and the spatial database can then be built for the environment analysis and water and land management.

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Output จากโครงการวิจัยที่ได้รับทุนจาก สกว.

1. ผลงานตีพิมพ์ในวารสารวิชาการนานาชาติ

   1.1 **Achalakul T.**, B. Sirinaovakul, and N. Nuttaworakul, Virtual Laboratory: A Distributed Collaborative Environment, *Journal of Computer Applications in Engineering Education,* Vol.12:1 (2004), pp. 44-53.

   1.2 **Achalakul T.,** S. Taweesuk, and R. Sarochawikasit, The Parallel Image Fusion Algorithm for Land Use Classification, *submitted to Computers and Geosciences: An International Journal*, June 2004.

2. การนำผลงานวิจัยไปใช้ประโยชน์ในเชิงวิชาการ

   ได้มีการนำผลการวิจัย (virtual laboratory platform) ไปใช้ประกอบการทำวิจัยและการเรียนการสอนดังต่อไปนี้

   2.1 การทดสอบประสิทธิภาพการเรียนการสอน online ผ่าน virtual classroom ในวิชา Predicate Calculus (FOPC) ของมหาวิยาลัยเทคโนโลยีพระจอมเกล้าธนบุรี ผลการทดสอบได้มีการนำเสนอในการประชุมวิชาการ ในประเทศ อินเดีย

   Songsriwittaya A., B. Sirinaovakul, and T. Achalakul, "Assessing the Effectiveness of Knowledge Sharing in Distributed Collaborative Learning", *International Conference on Fourth Wave Education*, Rajkot, India, Jan 2004.

   2.2 การทดสอบประสิทธิภาพการทำวิจัยร่วมกันของนักวิจัยที่อาศัยอยู่คนละสถานที่ผ่านทาง virtual laboratory โดยได้มีการทดลองทำงานวิจัยย่อยระหว่างนักวิจัยในประเทศไทย และประเทศเกาหลี ในหัวข้อเกี่ยวกับ image fusion ผลจากการวิจัยได้มีการนำเสนอใน การประชุมวิชาการในประเทศเกาหลี

   Srinilta C. M. Park and T. Achalakul, "A Concurrent PCT for the Analysis of Multiresolution Data", *The 2003 International Technical Conference on Circuit/Systems, Computers and Communications,* Kang-Won Do, Korea, July 2003.

3. การเสนอผลงานในที่ประชุมวิชาการ

   3.1 Wiyarat T. and **T. Achalakul**, "The Wavelet-based Fusion Model for Multi-resolution Satellite Data", 5^{th} *International Conference on Software Engineering, Artificial Intelligence, Networking, and Parallel/Distributed Computing*, Beijing, China, June 30-July 2, 2004.

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ภาคผนวก

(Reprint และ Manuscript ของบทความสำหรับการเผยแพร่)

วารสารวิชาการนานาชาติ

1. Virtual Laboratory: A Distributed Collaborative Environment
2. The Parallel Image Fusion Algorithm for Land Use Classification[3]

การนำเสนอผลงานในการประชุมวิชาการนานาชาติ

3. Distributed, Real-Time Collaborative Environment
4. The Wavelet-based Fusion Model for Multi-resolution Satellite Data

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[3] The manuscript is under the reviewing process

Virtual Laboratory: A Distributed Collaborative Environment

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ABSTRACT: This article proposes the design framework of a distributed, real-time collaborative architecture. The architecture concept allows information to be fused, disseminated, and interpreted collaboratively among researchers who live across continents in real-time. The architecture is designed based on the distributed object technology, DCOM. In our framework, every module can be viewed as an object. Each of these objects communicates and passes data with one another via a set of interfaces and connection points. We constructed the virtual laboratory based on the proposed architecture. The laboratory allows multiple analysts to collaboratively work through a standard web-browser using a set of tools, namely, chat, whiteboard, audio/video exchange, file transfer and application sharing. Several existing technologies are integrated to provide collaborative functions, such as NetMeeting. Finally, the virtual laboratory quality evaluation is described with an example application of remote collaboration in satellite image fusion and analysis. © 2004 Wiley Periodicals, Inc. Comput Appl Eng Educ 12: 44–53, 2004; Published online in Wiley InterScience (www.interscience.wiley.com); DOI 10.1002/cae.20008

Keywords: computer supported cooperative learning; distributed object technology; software quality evaluation; software usability; virtual research community

INTRODUCTION

Computer supported cooperative work (CSCW) [5] is the concept that can be used to create a computer-based, distributed, virtual workplace, where researchers/analysts can meet and interact with one another via the virtual agents or objects. This concept focuses on putting interactive, dynamic representations of data and people into virtual landscapes and offers the powerful mechanisms for navigation, exploration and communication. Applications of the collaborative environments include distance learning, remote

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research, virtual shopping, telemedicine, psychotherapy, games, flight simulators and military.

In this study, we present a design framework and an implementation detail of a virtual research laboratory. The goal is to facilitate a joint effort among the dispersed researchers in data analysis. The collaborative framework is designed to allow information to be analysed and disseminated in real-time, to multiple observers and controllers, thus, providing a collaborative problem-solving medium with the ability to sense, interpret, and analyse data. The processing facility can be centralized while the computing results are distributed. Our virtual laboratory is a solution for building a bridge for accessing, transferring and manipulating data/objects via the Internet. The implementation is done based on the concepts of ‘‘objects’’. Every component in the system is an object with a set of interfaces, which are defined based on the functionality it provides. The system consists of several types of objects, namely, the security officer, the broadcaster, the listener, the client, and the communication channel objects. These objects are used to facilitate the sharing of information and applications. The real-time, collaborative research session can be created and shared among a group of participants, where each participant can gain an access to a session over the Internet.

RELATED RESEARCH

With the rapid growth of geographically dispersed research communities, many researchers in the CSCW area have focused their effort in designing the system, the network and the software architecture for the collaborative and real-time environment [3,4,7,8,12].

A study by Ho [10,15] reported the work that facilitates the research collaboration between universities and industries. The collaborative infrastructures included mechanisms for supporting the virtual workplace, such as adding members, controlling access, maintaining a discussion space and managing the shared document. Foster [8] outlined the important trends in the development of a collaborative system based on distributed computing concepts, which have changed the basic of computing from desktop-centric to network-centric. He also identified a set of fundamental mechanisms that are needed for complex computational environments, namely, communication, configuration, discovery, naming, navigation, persistence, resource brokering, security and sharing. Chen [4] defined the main features of distributed collaborative environment to be the collaboration management and the connection management. The task of the collaboration management is to create behavioural specifications of collaborations, to translate the specifications into a set of operational attributes and constraints as well as to instantiate the collaboration. The connection management task deals with the progress in instantiating the environment. Aoki [1] described the study in building collaborative environments for supporting web users on a real-time browser. The work has adopted a proxy-based approach, where normal web browsers are supported without any modifications or plug-ins. Java applets are used to provide communication capabilities. Collaborative functions are implemented in JavaScript by using the dynamic HTML functions.

Sinn [16] introduced the basic architecture for the heterogeneous distributed object technology. In this study, each computing involves a server, a client, an interface and a network object. A network and an interface objects provide abstract layers to allow users to access and process data in a heterogeneous system using the same interface. Beca [3] demonstrated how the distributed object technology could be efficiently applied to the process of building a collaborative application on the Internet. In their study, Tango beans components are used to develop collaborative tools and applications for synchronous distance learning and web conferencing. Tango Beans is a set of components based on the Tango Interactive framework [3] that has been implemented to facilitate the rapid development of the collaborative applications. Tango Beans provides a high level interface to the collaborative services offered by the Tango Interactive framework. The technology consists of two components: TangoBean and ObjectPipe. Their main goal is to enable an easy creation of the collaborative applications for the Tango Interactive environment using visual programming tools. An application constructed using Tango Beans can communicate with other applications started in the same collaborative session. It can also access session information. Tango Beans are based on Java Beans-software component model, which allows a quick development of sophisticated tools through visual programming methods. However, Tango Beans has a limitation that the technology can only be used with Java applets and applications. In other words, applications developed using other languages cannot utilize Tango Beans collaborative components.

In this research, we proposed a design framework that adopted the component architecture concept defined previously while focusing on the integration and the leveraging of the existing tools. The COM/DCOM standard [9,13,14] has been selected in our design because of its compatibility with most languages.

Moreover, COM/DCOM allows us to take advantage of the Microsoft technologies, such as the plotting and the presentation tools, and thus, reduces the development time and cost.

THE DESIGN FRAMEWORK OF THE VIRTUAL LABORATORY

The international technical conferences as well as seminars and tutorial sessions today have brought researchers from all over the world together for a mutual benefit of sharing information and discovery. One of the goals of such events is to establish the collaboration between different research communities. In order to facilitate efforts in remote collaborative researches, while cutting down the time and the cost spending in laboratories visits, the design framework of the virtual research communities is proposed. The framework should allow the researchers to efficiently communicate in real-time. The researchers should be able to exchange voice, video, text and images, and to carry out the technical discussions with ease. The experimental results should be shared and the computation should be collaboratively observed.

Figure 1 shows the architectural concept of our virtual laboratory. A heterogeneous collection of networked PC's, workstations, and shared memory multiprocessors (SMP's), provides the computational resources for high-performance concurrent algorithms. Multiple real-time sensors may be connected at arbitrary points in the network and interrogated through computation. Multiple analysts may connect to the running computational session using a standard web-browser at arbitrary points in the network. A designated analyst (the first connection made to the system) controls the access to a session. Multiple analysts may subsequently connect to a computational session from remote computers and are provided with a read access. Coordination and discussion between analysts are carried through a chat and whiteboard applications. Computing, plotting, spreadsheet and presentation tools are also provided in the environment for the real-time research coordination.

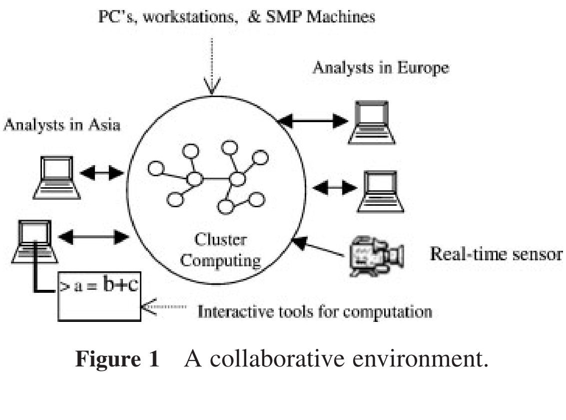

Figure 1 A collaborative environment.

The designated analyst is provided with the privilege to control the interaction modes and computation. The privilege can be handed off to other participants as needed. The same view of computation is available to all the analysts. Each analyst is able to manipulate data through a set of tools and share results. The standard used in our designed infrastructure for the virtual laboratory architecture can be described as follows:

> The basic design is to view everything as component objects: PCs, SMPs, a collection of analysis techniques, interactive tools and a real-time sensor. In our design, an application can propagate its events to another application operated by another session participants, whereby the events are forwarded to appropriate components. This model allows actions in one application to be a mirror image of another. Another useful feature in the component model is the ability to transfer arbitrary data among applications. For example, a drawing created inside the virtual laboratory can be transferred to all participants who logged on at the latter time.

In respect to the idea described above we adopted Microsoft component model, COM/DCOM. COM represents all components reside in different platforms and DCOM is a mechanism defined to support communication across platforms. When a client process tries to communicate with a server process, COM will format the data getting it ready for remote sharing. Then, DCOM facilitates the interaction through Object Remote Procedure Call (ORPC). COM/DCOM is a mechanism that can work well with Internet-based applications because it can work natively over the HTTP protocol and firewalls. In other words, a COM component will be able to go through the firewall just like a HTTP object, and thus, allows a smooth integration of the client-side components to the collaborative architecture [12]. In addition, DCOM is a Microsoft object model that has been mostly implemented. It is relatively robust, and easy to maintain and extend. Being a Microsoft product, DCOM also gives us an advantage of being able to leverage most of Microsoft analysis and displaying tools, which, in turn, reduces our development time and cost greatly. The alternatives to DCOM standard that we studied are CORBA and JAVA RMI. CORBA, although offers good concepts, a large portion of the standard has not yet been implemented. Whereas JAVA RMI has an unpredictable runtime behaviour, the property inherited from Java Virtual Machine [5], which is not acceptable for real-time applications.

To demonstrate the capability of our virtual laboratory, we explore an application in distributed-collaborative research. The centralized computing facilities are used as our test-bed. The computing platform provides the raw computational resources for any concurrent algorithms or analysis techniques. The centralized resources are used to compute and to create a series of analysis results. Multiple analysts can, then, connect to the system to view the results using standard web-browsers. In other words, the collected results can be processed and distributed for collaborative research over the Internet. To allow the sharing of these results residing in the centralized computing units, The DCOM standard is employed as shown in Figure 2. The server component consists of a computing object, a security officer, a broadcaster and a listener. The client components can instantiate collaboration by communicating with the caller objects. The caller object can, then, sends a client call to the server through DCOM. All client requests are sent to the listener, a mechanism used for monitoring calls. The listener communicates with the security officer to verify the client's access right, which is kept in the database object. If the access is granted, the new session is started. The clients can then work collaboratively via several applications: chat, whiteboard, audio, video, file transfer and application sharing. Using the Channel Object, the applications and the analysis results can be shared and researchers can edit contents collaboratively. When the channel object is called, the broadcaster sends the shared data to the requested clients. All the intra- and inter-component communications are done through DCOM layer and the Internet is used as a main communication medium.

To support this architecture, a collection of collaborative tools is proposed. We leverage several existing technologies to create tools that integrate collaboration features into our system. NetMeeting Software Development Kit (SDK) [18] is employed as the core technology.

THE IMPLEMENTATION DETAILS

The implementation of our virtual laboratory is done based on the concepts of ‘‘objects’’. Every component in the system is an object with a set of interfaces, which are defined based on functionality it provides. The system object hierarchy is illustrated in Figure 3.

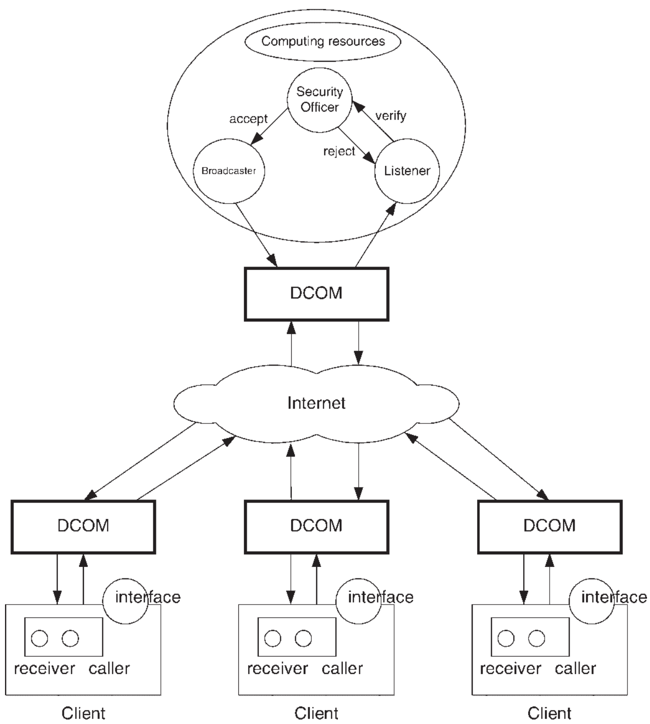

Figure 2 DCOM for virtual laboratory.

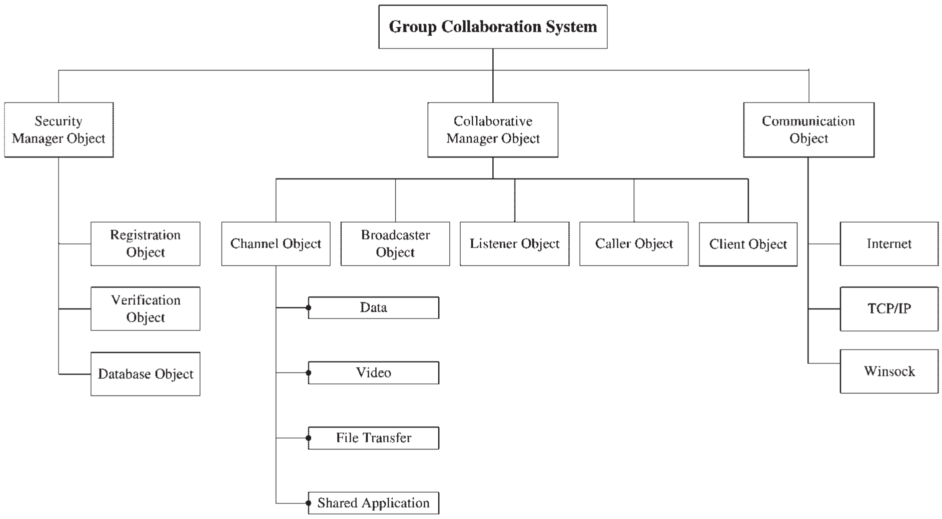

Figure 3 System objects hierarchy.

Each object communicates and passes data with other objects in the hierarchy by a set of interfaces. The object instance manager is implemented to manage the object's interface pointer. Its job is to create a connection to the sink and to pass calls to each object's interface.

From Figure 3, the client joins a collaborative session by communicating with the caller object. The caller object sends the client calls to the listener. The listener forwards the calls to the security officer object, whose job is to verify an access right with the database object. Only the authenticated clients can gain an access to the channel objects in the system. The channel object provides services such as data transfer and application sharing. The broadcaster object is then invoked. This object opens the link to the channel object and thus, allows the client to see the broadcast information in the current session. The detail functionalities of each object can be described as follows:

The security manager object maintains the member lists of the system. It monitors whether each user's request should be authorized. This object also handles the registration for new users and maintains the users' database. The following pseudo code shows how the security object works.

Activate Database object
Case: member login
Get Username and Password
If valid user then
        Accept calls
        Connect to the collaborative manager object
else
        Reject calls
End if
        Case: new user registration
        Get new user information
        Save to database

The collaboration manager object is the main component that conducts the collaboration sessions in a virtual laboratory. The collaboration manager is responsible for initialising and managing the collaborative sessions. It also manages incoming and outgoing calls, controls data distribution among all session participants, and manages local computing resources. The collaboration manager tasks can be listed in the following pseudo code.

Begin
        Accept a session request
        Get environment information
        Initialize the system variables
        Create a collaboration session
        While (not terminate)
        If call request
                Service call
                Lists all calls in progress
        End while
End

The caller object is a mechanism used to control the incoming and the outgoing calls to the collaboration session. The caller has two major functionalities: call enumerator and call notification. The call enumerator object lists active calls in a collaborative session, while the call notification object handles information about the incoming and the outgoing calls during group participation, which allows the designated participant to accept, reject and cancel new calls.

```
Begin
    While (not terminate)
        If (incoming call)
            [state, name, address] = GetCallInformation()
            user = GetUserData()
        if (accepting call)
            call security officer object
        else
            cancel call
        end if
    end while
End
```

The client object provides the interfaces to members of a collaboration session. The interfaces include methods, such as information retrieval, which is used to retrieve member identifier, name, address and shared state.

The channel object allows each participant to share resources, such as custom applications, data, file, video and audio. It provides a set of interfaces, which can be used to manage communication in all channel types. The channel object will be called whenever a channel is to be added, removed or updated. A pointer to a new channel is sent as a parameter to the collaboration manager for all session members to use. The manager will respond to the notification based on the type of the channel. The following pseudo code shows how channel interface works.

```
Begin
  While (not terminate)
      Case add: getChannelType
                CreateChannel
                ActivateChannel
                List = getSessionParticipantList
                AddParticipant(List)
      Case remove: List = getSessionParticipantList
                NotifyParticipant(List)
                RemoveParticipant(List)
                RemoveChannel
      Case update: If (channel active)
                   getChannelType
                   List = getSessionParticipantList
                   UpdateChannel
                   NotifyParticipant(List)
                 End if
  End while
End
```

The Channel object in our system can be divided into four types: the data channel, the video channel, the file transfer channel and the shared application channel objects. The data channel object provides methods for data sending and receiving among all participants. This object controls and interleaves all data exchanges for chat and whiteboard applications. The video channel object manages the exchange of the video data. The object mainly handles video conferencing applications. The file transfer channel object manages the file exchange by providing supports for sending and receiving different type of files similar to the FTP application. The shared application channel object allows participants to share any custom application during run time. All participants can view the same data and actions as the program progresses; e.g., the researchers can collaboratively provide the input and monitor the results of a computation. This channel object provides methods to allow the designated client to set the level of control that each participant has on a shared application. There are two types of messages circulated among the participant list in this channel object: state change and member change. The state change message is used to notify all participants in the list whether the current application is being shared. The member change message indicates the changes in participant list (add, remove, update).

The broadcaster object handle information broadcast. The communication mechanism can be described in Figure 4.

Each client has two components, which are the sink object and the client object instance. The client object instance is used to manage actions on share objects. Any action applied on the shared object is forwarded to the server side, in order for the action to

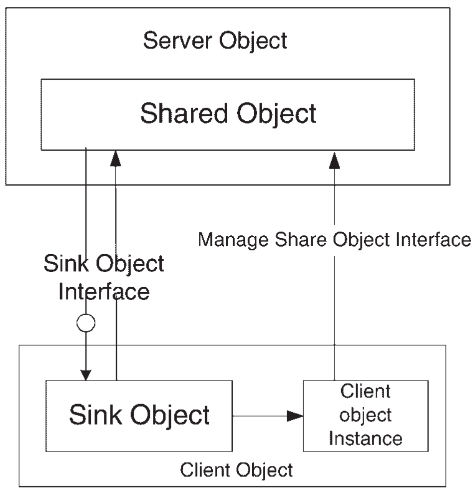

Figure 4 The broadcasting mechanism.

be recorded and broadcasted. The sink object is connected to a communication point, which is used to echo interactive mouse-motion events across the network. All the events are first sent to the server object and then are broadcasted to the clients in the session.

The communication object handles the low-level socket communication. The NetMeeting communication technology is leveraged in our system. The transmitting protocols available in this object include TCP/IP for data transmission and UDP for audio and video transmission.

QUALITY EVALUATION WITH AN EXAMPLE APPLICATION

Quality evaluation is performed on the virtual laboratory to determine whether our design has captured the objectives and is suitable for the tasks of remote research collaboration. During this evaluation process, the system usability is measured. System usability is defined in ISO 9241 draft standard as the ''extend to which a product can be used with effectiveness, efficiency and satisfaction in a specified context of used'' [6]. In this section, we attempt to verify our system usability using the example application of a remote collaboration in satellite image fusion and analysis. This particular project required the knowledge from multiple disciplines, namely, image fusion, remote sensing, concurrent programming and mathematics. A collaborative effort was then put together between a scientist in the department of computer science and engineering, Korea University, Korea, and a group of engineers from King Mongkut's University of Technology Thonburi and King Mongkut's Institute of Technology Ladkrabang, Thailand. The preliminary goal was to establish an approach to the fusion of multi-spectral image for satellite image analysis. The algorithm was designed to enhance the spatial resolution of a multi-spectral image and to represent the embedded information with a minimum number of images. To increase the computing efficiency to the point where a real-time analysis is possible, the concurrent programming approach has also been considered. The collaborative framework of the project can be depicted in Figure 5.

The desire outcome is to establish an effective fusion model. With this objective in mind, we have designed the computer-based collaboration method on top of our virtual laboratory concept. The virtual research community between multiple campuses was then, established. The custom web pages with the embedded Active X control components were developed to facilitate the information sharing. The community memberships were granted based on our security objects. The laboratory context of use for this multi-discipline project includes the model design discussion, the experiment observations, and the results sharing. Several tools provided in the virtual laboratory were used as vehicles toward this context of use as shown in Figure 5.

The first phase of the project was the remote discussion to develop the suitable fusion model. Several suggestions on signal processing techniques, such as wavelet transform, discrete cosine transform and principal component transform (PCT) have be traded via the chat, the whiteboard and the presentation tools. The discussion was successfully carried out and the preliminary fusion models were exchanged via the file-transfer tool. The conclusion has been derived collaboratively to develop the fusion model

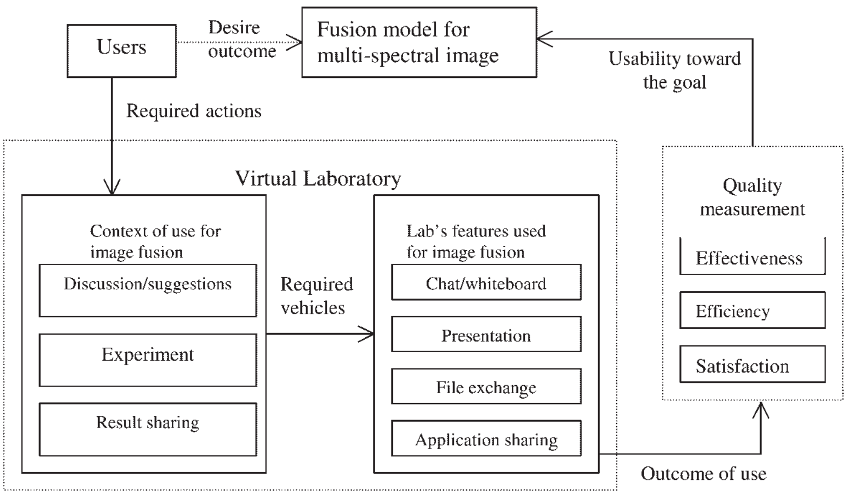

Figure 5 Collaborative framework for image fusion application.

based on the PCT [11]. A satellite multi-spectral image was the input to our fusion model. Eigenvalue was the feature of interest. The PCT-based model took the source image and computed the eigenvalues. With respect to these eigenvalues, the model then created a collection of images in the feature domain. Each created image was called the principal component. Due to the statistical properties of the PCT, the information embedded in each frame of the multi-spectral input image was pushed toward the front principal components.

After the fusion model was developed, several experiments have been observed remotely in real-time through the application broadcast mechanisms. Mathlab was used as the main tool. The researchers exchanged the ideas through the shared screen of Mathlab. Chat tool was also used, in parallel, to carry out the discussion. The experimental data (image and text files) were transferred on a regular basis. The interactive experiments were performed on a set of compressed and scaled-down images (size of less than 200 kb/image) for convenient in transferring. However, the full size images (70 MB/image uncompressed) were used to produce the final result. The fusion algorithm and the results were cooperatively analysed based on the statistical properties of the PCT. Microsoft Excel was used primarily in this phase.

The experimental results show that more than 98% of the information, embedded in the satellite image set, is pushed into the first principal component. There is almost no significant variance left in the latter components. The conclusion can, thus, be made that our fusion model successfully summarizes the spectral information from the multi-spectral satellite scene and presents it in the few resulting images. These images offer a significantly improved contrast and details compare to the original scene, and can later be used by the scientist in land use classification applications. The experiment observation also suggested the need for the concurrent programming technique to be adopted to enhance the computing speed. The concurrent algorithm was then collaboratively designed. This fusion research project was successfully carried out entirely in the virtual laboratory, presenting a major cut-down on time and expense spending on campus visits. The details of the project are reported in [17].

During the course of this research collaboration, the outcome of use for the virtual laboratory was recorded in terms of effectiveness, efficiency and satisfaction. The Heuristic evaluation [2] was applied by using questionnaires on a group of 10 evaluators involving in the project. The evaluators are researchers, engineering students and faculties, and a project administrative person. This group of people has a wide variety of computer skill, ranging from beginner to expert. However, the majority were expert users. The evaluation sheet was used to quantify the judgment on each category of quality measurement presented in Figure 5. The system effectiveness was measured upon the percentage of communication goal achieved and the percentage of success in completing the tasks in each phase of the project. Questions asked involved around the effectiveness and the convenience in using the tools, carrying out the discussion and sharing the data of different types. The efficiency was measured on the time and the cost of completing the task in the virtual laboratory against the use of the traditional means. The satisfactory level was measured using questions related to rating scale and frequency of errors and complaints. The questionnaires also included the questions about the overall judgment on the system functionality, maintainability and flexibility. The questions in this category emphasized on the ease of use, the feature availability and the system presentations. The subjective judgments on the system were quantified by assigning points between 1 and 5 for each question in each category. The quantitative evaluation was then calculated by the formula $e = \sum r_i$, where r_i was the average score of questions in each category. With the highest score being 5, the result of the survey is presented in the following table.

	Effectiveness	Efficiency	Satisfactory	Overall judgment
Average values	3.33	4.01	2.9	3.4

Given all categories an equal weighting factor, the overall usability of the virtual laboratory is measured at 68%, which is satisfactory for this beta version. The efficiency rating received the highest score at 4.01. This number reflects the good improvement in terms of time and cost for collaborative research in the virtual laboratory compare to other traditional ways. While the efficiency was rated high, the satisfactory level was below our expectation with the score of 2.9. Based on the oral suggestions made during the evaluation process, the low level of satisfaction causes by the lack of customized graphical user interface (GUI), and offline messaging services. The GUI and Online help improvement were also recommended. These suggestions have been taken into consideration for our next release. It was also noted that the video feature introduced a low frame rate and poor quality, which made video conferencing inconvenient. However, it is hard to overcome this problem due to the use of the Internet and the network speed on campus. The Internet is a best-effort service and does not offer any quality of service guarantees. Loss of data packets during transmission is likely to happen, which causes the most trouble for real-time video. Moreover, the network technology provided on the King Mongkut's University of Technology Thonburi campus allows the maximum speed of 18 MB/s, which was the bottleneck in video transmission. The effectiveness rating of 3.33 was acceptable for our initial system. Several improvement including video/voice transfer rate, and concurrent collaborative sessions were being incorporated to raise the effectiveness level. With the limited graphical user interface and online help features, the overall judgment rating of 3.4 was above our expectation.

In conclusion, the evaluation process presents a good effectiveness, efficiency and overall judgment values, which implied that our virtual laboratory is suitable for use in remote research collaboration. The features available in the system has answered the needs of real users carrying out real tasks in real research environment.

CONCLUSION

In this study, we proposed a web-based collaborative framework for the construction of a virtual laboratory and its implementation and evaluation details. The virtual laboratory is designed to facilitate coordination among dispersed researchers over the Internet. Our system has the advantage of eliminating excessive travelling costs and time constraints in the traditional remote collaborative research.

The architectural concept of our system enables multiple analysts to collaboratively work through a standard web-browser using a set of tools, namely, chat, whiteboard, audio/video exchange, file transfer and sharing application. Our collaborative system is designed by viewing everything as a component or an object. The component object model is adopted as our based technology for building the cooperative objects. Each of these objects communicates and passes data with one another via a set of interfaces and connection points. The object hierarchy of the system consists of the collaboration manager, the system officer, the clients, the channel object, the listener and the broadcaster.

We constructed our collaboration features in the system by leveraging several existing technologies. The principal technologies are: (1) the NetMeeting SDK, used to embed the Active X control and to integrate the collaboration features; (2) the database system, used to serve as a security officer and to verify user access right; and (3) the web server and browser, used to support interaction and communication. The Internet is used as the main communication medium in our system.

As our system is based on the Component Object Model, it is relatively robust, easy to maintain and easy to extend. The object model also provides an advantage of being able to leverage most of the Microsoft analysis and displaying tools, which greatly reduce the development time and cost. The collaborative system can be applied for several applications, such as E-learning, discussion group, help desk and collaborative research.

Finally, we presented the software quality evaluation experiments on the virtual laboratory. The usage of user questionnaires evaluates the system efficiency and effectiveness as well as users satisfactions. Although, there are still rooms for improvement, the evaluation results have been satisfactory, verifying the suitability for use in remote collaborative research.

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The Parallel Image Fusion Algorithm for Land Use Classification

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Abstract

This paper discusses a parallel algorithm to the fusion of the multi-spectral image data for the analysis of satellite images. The algorithm combines the spatial-frequency wavelet transform and the maximum selection algorithm. A high quality achromatic image that suits the human visual system was generated as the resulting image. To demonstrate the algorithm, it was applied to the multi-spectral image taken from an 8-band Landsat ETM sensor. The image of Chiang Mai, Thailand is used as our experimental scene due to a good mixture of foliated and urban areas contained in the scene. The performance of the algorithm was measured on a distributed collection of computers that are connected through LAN. The algorithm was assessed from both the perspective of image quality using the SNR and the performance and scalability. The experiments show that our parallel wavelet-based fusion algorithm scaled well in a network of computers and produced a good quality resulting image, which can benefit several applications in environmental planning, assessing and monitoring, and natural resource management.

Keyword: Concurrent Computing, Discrete Wavelet Transform, Multi-spectral Image Fusion, Land Use Classification

1. Introduction

Research and development in the industries, and academics today highly depends on information extraction technology. Information can come in many different forms, i.e. number, still image, voice, video, etc. In order for the researchers to fully utilize available information, some forms of information fusion are required.

Information fusion refers to the combinational process of information from different sources into one representational format.

In this work, we focus on the fusion of image information. We use the term image fusion to denote a process of generating a single resulting image which contains a detail description of the scene from a set of source images. Images can be collected at different wavelengths, where each contains different information. The fused image should contain most if not all important information presented in the scene, and thus, useful for human and machine perception. For large image sets, such as those used in remote sensing, the overwhelming amount of embedded data make it extremely difficult for researchers to perform a data analysis. In order to alleviate the problem, we seek to develop an automated technique that fused the data together. Our fusion technique can be used to enhance data in a variety of applications in the environment planning including land use classification. Data fusion can increase the effectiveness of the environment impact assessment that would require the process of remote sensing data analysis. The major advantage of the technique is that it allows the image analysts to increase resolution in any dimension (spectral or spatial) without having to sacrifice the fine resolution or spectral integrity.

Many image fusion processing and analysis techniques in recent literature make use of the information that contain in the coefficient of the transformed domain. This paper proposes a parallel wavelet-based technique for multi-spectral image fusion. A multi-spectral image is a set of images of the same scene, which are taken at different wavelength. The fusion concept allows us to take advantage of fundamental characteristics of images from different wavelength and produce the new image which contains the most of the important information analyzes from original image set. The wavelet-based image fusion involves transformation of each source image from the spatial domain to spatial-frequency domains using the wavelet transform. The composite representation is then constructed using a wide variety of fusion rules, and the final fused image can be obtained by taking an inverse transformation. In the case of fusing images from two different sensors, the algorithm will enhance one sensor image using edge detail to match another. Wavelet-based methods are used in image fusion and analysis because the methods produce multi-scale images in the transformed domain, which provide information on the sharp construct changes as well as information in both spatial and frequency localization. A multi-scale representation is also useful for detecting different components in an image using different entropy.

The wavelet transform, however, has high computational costs because it involves pixel convolution. The performance requirement discourages the use of our algorithm in real-time applications. To improve the performance, we explore the use of a parallel algorithm employing low-cost, commercial-off-the-shelf computers connected using a standard LAN.

2. Background Study and Related Research

Data fusion is one of the image processing techniques that can be used to enhance data in a variety of applications ranges from hospital pathology to land use classification. With the rapid growth of the fusion applications, many researchers have focused their effort in designing the effective system for the real-time environment**.**

A multi-spectral image may be fused using various techniques: data level fusion, feature level fusion, and decision level fusion [Hall 1997].

Data Level Fusion. Fusion at this level, a raw image acquired from multiple sensors is fused together on a pixel-by-pixel basis. The algorithms concern fusion in either spatial or frequency domain. In spatial domain, techniques usually involved image arithmetic (addition, subtraction, multiplication, and division) on the pixel intensity from two or more bands. Band differences or band ratios [Richards et.al. 1998] are the most useful of these approaches and are often used to enhance spectral reflectance differences for rocks, soils, and vegetation. Unfortunately, it is unclear how to define effective fusion arithmetic for a large number of bands. Empirical selection of arithmetic rules may introduce losses in pixel contrast, and important spectral information is thus lost. An alternative fusion technique that uses maximum contrast selection [Peli 1999] may involve a contrast measurement calculation for each pixel at each scale and orientation in all spectral bands.

Fusion in frequency domain, an original image is transformed to frequency or spatial-frequency domain, where contrast and object characteristics are readily available. The method of choice is application-dependent; however, the algorithms typically follow the general schema described in Figure 1.

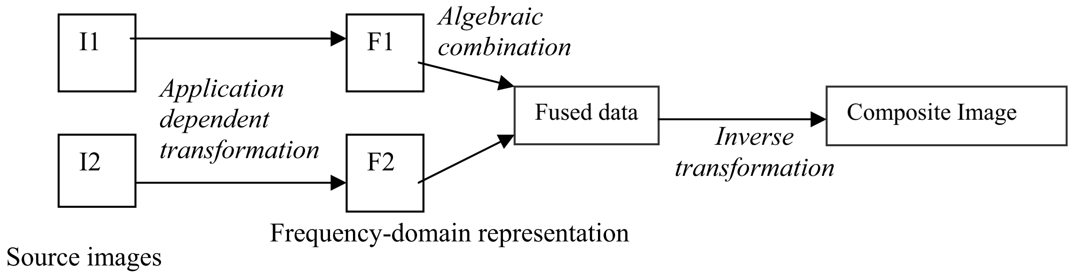

Figure 1. Multi-sensor Fusion

Source images are usually transformed using Fourier [Gonzalez et.al. 1993], Laplacian [Burt et.al. 1993], or Wavelet transforms [Prasad 1997]. The representations in the transform domain are then combined using algebraic rules to form a single fused data set. This result is then inversely transformed to obtain a final visible image. The Fourier transform, although efficient, does not correlate high frequency components with the original spatial information and hence cannot locate the position of an interesting attribute within an image. This problem has been resolved using pyramid-based methods such as the Laplacian and Wavelet transformations. The Wavelet transform has several advantages over the Laplacian: it provides a more compact representation, separates spatial orientation in different bands, and de-correlates interesting attributes in the original image.

The algebraic rules typically weight images in the source because of the relative importance of specific spectra. For example, in concealed weapons detection, images in the millimeter wave spectrum extenuate metallic objects and are weighted higher in order to show them on the background of visible images representing people [Zhang et.al. 1997]. The algebraic rules may be based on pixel intensity [Paval 1991] or on some measure of contrast [Toet 1992]. This latter concept allows the selection of the spectral band that should dominate in the fused image. One interesting method is the maximum selection rule introduced by Burt [Burt 1993] for combining the coefficients of Wavelet and Laplacian transforms.

Feature Level Fusion. At the feature level, raw data will be transformed in the output into a representation such as image segments or signal amplitude or as shape, length, or orientation of objects in an image. The typical algorithms used in this level are parametric templates [Fukanaga 1990], hierarchical clusters [Everett 1980], neural networks [Kerr et.al. 1995], and knowledge-based approaches [Benfer 1991]. Parametric templates are often used because of their simplicity. The effectiveness of these methods depends upon the distribution in a feature space: if the distribution is low, the overlap will introduce ambiguity that may not be resolvable. To enhance the result with little added complexity, the hierarchical cluster method can be used. In this method, a cluster is an abstract description of a set of objects in the image that may be divided into sub-clusters by virtue of application-dependent parameters that discriminate objects.

An alternative method is to use Artificial Neural Networks (ANN), which performs a nonlinear transformation between an input vector and an output feature. This method can produce the required output more efficiently than most other approaches. In some medical applications, multiple computed tomography images taken from many different planar views, angles, distances, and spectrums are used as inputs to this algorithm. The output is a computed tomography image that has a clearer view and enhanced quality. Unfortunately, a considerable level of training is required to achieve the transformation function. A training set is made up of (X_i, Y_i) data pairs where Y_i is a set of output associated with the input vector $X_{i.}$ The association functions between the input and output vectors are generated during the training session. After training is performed, the ANN can construct a novel CT image for any given inputs within seconds. To start the training procedure, the input images are fed through the network, where random interconnection weights are generated. The interconnection weights are adjusted throughout several iterations. The association functions are determined when the root-mean-square error is less than a certain limit. These association functions will later be used to construct output images from any given set of inputs. The root-mean-square error, C, is calculated as follows:

$$C = \{ [1/(N*J)] * [\Sigma\Sigma(D_{n,j} - Y_{n,j})^2] \}^{1/2}$$

where J is the number of nodes, N is the number of patterns in the training set, $D_{n,j}$ is the expected jth output node value for the nth training set pattern, and $Y_{n,j}$ is the actual output value. The interconnection weight values are adjusted as follows:

$$w_{i,j\,new} = w_{i,j\,old} + \eta\sigma_i x_i + \alpha(w_{i,j\,old} - w_{i,j\,previous})$$

where $w_{i,j\,old}$ is the present weight value, and $w_{i,j\,previous}$ is the weight value before being adjusted to $w_{i,j\,old}$; σ_i is the error difference in the ith node multiplied by the derivative sigmoid activation function:

$$\sigma_i = f'(y_i)(d_i - y_i)$$

The magnitude factor of each adjustment is η, while α provides an impetus to the weight adjustment. Several thousand training iterations may be required, and thus a substantive computation is required in the training process.

Knowledge-based approaches are alternatives that emulate the cognitive processes used by humans. These approaches emphasize the use of a set of production rules, frame representations, and computational logic. Unfortunately, considerable training is also required for these techniques.

Decision Level Fusion. At the decision level, sensor data is processed individually and an identity declaration is performed by applying voting techniques [Hall et.al. 1990], scoring models, or other *ad hoc* methods. Voting techniques provide discrimination by a simple majority determination, where the most likely object is detected; scoring models form a weighted sum and determine the maximum weighted score.

The preference for one of these alternative approaches is highly application-dependent. According to a survey produced by Hall and Llinas [Hall 1997], in the sample space of 30 fusion systems there are over 75 algorithms used; no single algorithm can satisfy all of the needs [Agarwal 1994]. However, most the image fusion schemes described have a common problem: they are most effective when used on a small number of images taken from different sensors: for example, cameras with pre-selected IR, UV, or Visible filters. It is less clear how to adapt the algorithms to support a large number of input images.

In this research, we emphasized on the fusion of images, which is in the data level. We proposed a parallel fusion model based on a variation of the Daubechies's discrete wavelet transform and the implementation of the maximum coefficient fusion system. After considering all the advantages and disadvantages of each method, we feel that the DWT will introduce a relatively complete set of embedded information with little noise and also relatively efficient in computing.

3. Fusion System: the Design Framework

Wavelet transform is a multi-scale transform that produces the output representations in various resolutions. Each representation contains information in both spatial and frequency domains. The advantage of DWT is that the subsequence transform levels may provide additional details which are not available in the first transform level. In our research, we based our transform on Mallat's Algorithm. fusion framework can be described in Figure 2.

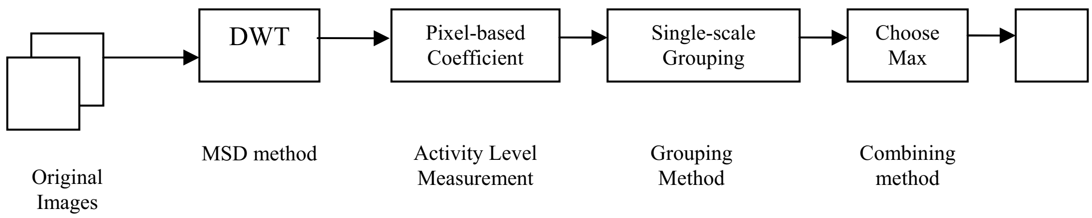

Figure 2. The Image Fusion Scheme

Mallat's Algorithm for DWT is an orthogonal transform, in the sense that each level of the decomposition will present different information. The algorithm is capable of providing additional information that may be embedded but not visible in the original signal. Thus, it is suitable for our fusion process. From our experiments with the Landsat ETM data set, we found that a 2-level decomposition is sufficient to bring out a significant amount of information.

From a two-dimensional signal c^{j+1}, the DWT will produce four separate signals representing the next level approximation coefficients c^j (low-low band), the vertical coefficient d^{j1} (low-high band), the horizontal coefficient d^{j2} (high-low band), and the diagonal coefficent $d^{j\,3}$ (high-high band). The equations are shown below:

$$c^j_{m.n} = \tfrac{1}{2} \sum c^{j+1} h_{k-2m} h_{1-2n}$$
$$d^{j1}_{m.n} = \tfrac{1}{2} \sum c^{j+1} h_{k-2m} g_{1-2n}$$
$$d^{j2}_{m.n} = \tfrac{1}{2} \sum c^{j+1} g_{k-2m} h_{1-2n}$$
$$d^{j\,3}_{m.n} = \tfrac{1}{2} \sum c^{j+1} g_{k-2m} g_{1-2n} \qquad \text{eq (1)}$$

From the equations, m and n represent the pixel coordinates (row and column), g defines the high pass FIR (Finite impulse response) filter and h defines the low pass FIR filter, j is the scaling function along the x-axis ($j = 0,1,2,\ldots,j-1$) and k determines the position of scaling function along the x-axis (k = 0,1,2,…,$2^{\,j-1}$). The signal reconstruction equation can be defined in equation 2.

$$c^{j+1} = \tfrac{1}{2}\left(\sum c^{j+1} h_{k-2m} h_{1-2n} + \sum c^{j+1} h_{k-2m} g_{1-2n} + \sum c^{j+1} g_{k-2m} h_{1-2n} + \sum c^{j+1} g_{k-2m} g_{1-2n} \right) \quad \text{eq (2)}$$

The low pass and the high pass FIR filters are masking filters of length N. In our work, $N = 25$ is used (convolving matrix of size 5x5).

The DWT is a recursive method over the spatial data. Each input image will be decomposed and down-sampled using the low pass and high pass digital FIR filters. The FIR filters construct a set of approximation coefficient and three sets of detail coefficients (horizontal, vertical, and diagonal), which provide the detail of image information at different scales. First, the row of the input image is convolved with filters, h and g, and the column is then down-sampled to obtain two sub-images whose horizontal resolutions are reduced by a factor of 2. The advantage of down-sampling is reducing image size, while maintaining the embedded information. Both sub-images are then filtered and down-sampled into four output images producing high-high, high-low, low-high, and low-low bands.

Activity Level Measurement. The activity level of wavelet decomposition coefficient reflects the energy in the space between the coefficients. Our work employed the coefficient-based activity (CBA). The technique considers each coefficient separately. Generally, for each image I, we denote the wavelet decomposition coefficient as D_I, and the activity level measurement as A_I. Let (m, n, k, l) indicate the index to wavelet decomposition coefficients, where m and n give the spatial position in a given frequency band, k indicates the decomposition level, and l denotes the frequency band of the wavelet decomposition representation. The activity level can be described by the absolute value of coefficient in the wavelet decomposition representation as shown in equation 3.

$$A_I(m,n,k,l)=|D_I(m,n,k,l)| \qquad \text{eq (3)}$$

Coefficient grouping method. After the decomposition process, we obtain a set of coefficients in several decomposition levels as illustrated in Figure 3. From the figure, all the shaded coefficients are related to the same group of pixels in the source image. The multi-scale grouping method utilizes coefficients across levels to form a group, which may maximize the chance of gathering all embedded information. However, since most of the information is more likely to be embedded in a higher level of the decomposition, we decided to experiment with the single-scale grouping method (joining only the coefficients from the same decomposition scale). With the Landsat data set, we found that applying the multi-scale grouping provided a similar result to the single-scale grouping method. Thus, we choose to work with single-scale grouping to take an advantage of the less required computation.

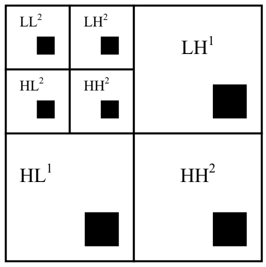

Figure 3. Wavelet decomposition coefficient grouping method

Coefficient combining method. After achieving the approximate coefficients and the group of detail coefficients, we attempt to create the resulting image by fusing multiple components according the fusion rules described below. Our image fusion algorithm assumes the following conditions: (1) the input images are of the same size. (2) All images are decomposed into a set of sub-images using discrete wavelet transform and all sub-images have the same resolution at the same level. (3) Coefficient component fusion is performed based on the high and low frequency sub-images. Let I_n be the coefficient matrix that represents the original image of frame n. I^h_n represents the high frequency components, and I^l_n represents the low frequency components. G_n denotes the gradient of the high frequency component I^h_n.

$$G_n = gradient(I^h_n) \qquad \text{eq (4)}$$

The fused coefficient of all high frequency components, F_h, can be calculated as shown in the following code fragment.

```
max = 0
for ( i = 0; i < n ; i++)
        if (G_max < G_i)
                max = i ;
F_h  =  I^h_max
```

The fused coefficient of all low frequency components, F_l, can be calculated as follows:

$$F_l = \max(I^l_n) \qquad \text{eq (5)}$$

Using the fused components of the low and the high frequency coefficients, the resulting image can then be generated by taking the inverse transform of both fused components.

$$\text{Result} = \text{inverseDWT}(F_l, F_h) \quad \text{eq (6)}$$

4. The Parallel Algorithm

The concurrent algorithm decomposes each image frame into sub-images, which can be operated on relatively independently. Each sub-image consists of a set of pixels. The allocation of sub-images to processors is managed through a variant of the manager/worker technique depicted in Figure 4 [Chandy et.al. 1992]. This strategy employs a manager thread that performs the above decomposition, and distributes sub-cubes to a set of worker threads. Each worker performs relatively independent components of the overall image transformation. A manager thread coordinates the actions of the workers, gathers partial results from them, and assembles the final resulting image.

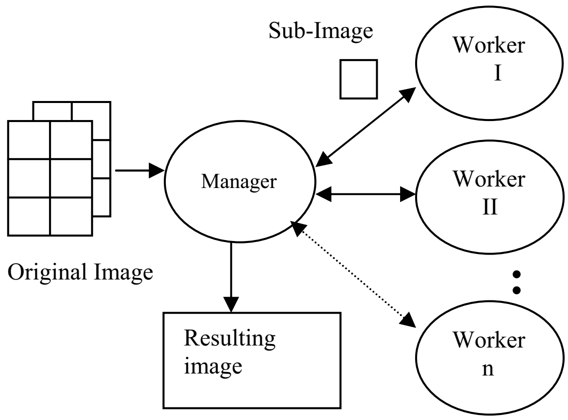

Figure 4. Manager-worker model

The main abstract code of the algorithm is shown in Program 1 and is executed at every processor on the network. The manager and workers are executed as independent threads with a single thread per processor. The manager abstract code is shown below in Program 2. The manager thread serves primarily to synchronize and accumulate partial results from the workers. The manager loads original image frames and then distributes them to a set of workers (line 4&5). It also synchronizes the calculation by making sure that the partial results are received from all workers before moving on to the next stage in the algorithm. When the partial results are returned (line 6), the manager applies the maximum selection rule (stated in the previous section) to form a fused coefficient set (line 7&8). The fused coefficient set is then divided into subsets (line 9) and the subsets are distributed once again to perform the inverse transformation (line 10&11). The final result is assembled after the all workers send back the partial results (line 12) and then is displayed (line 13).

```
main() {
        p = getMy ProcessorId()
        if (p == 0) {
                numSubImages = getNumSubImage (numWorker,
                                                        numPixel)
                manager(numSubImages, numWorker)
        }
        foreach remaining available processor
                Worker()
}
```

Program 1: Main

Each worker thread waits for the manager to send its part of image (line 1). Once the sub-image arrives, the convolution is performed to filter and to downsample the sub-image using Mallat's Algorithm (line 2). The activity level measurement and the coefficient single-scale grouping are then performed (line 3&4). The resulting coefficient matrix is sent back to the manager to be fused (line 5). The worker then waits for its next set of data (line 6). Once received, it applies the inverse wavelet transform to convert the coefficient set back to the spatial domain (line 7). The results are sent to the manager for displaying (line 8).

5. Image and Performance Evaluation

This section focuses on the image evaluation and algorithm performance. The previously presented parallel fusion algorithm is applied to the Lansat ETM+ satellite data. The Landsat ETM+ data set is commonly used by the environmental scientists to classify foliated and urban areas for map creation as it gives the multi-spectral information needed in the process. The data allows the analysis of a large region that includes more than one urban centers. The first part of the section describes common methods for image evaluation, the experimental data set and the resulting image evaluation. The second part presents the performance evaluation of the parallel algorithm.

```
manager(numSubImages, numWorkers) {

    coefficientCube = [][]
    coefficientFused = []
    finalImage = []
    foreach worker i {
       send (i, aSubImage)
       coefficientMatrix [i] = recv(i)
    }
    coefficientCube =  build (coefficientMatrix [])
    coefficientFused = maxSelection(coefficientCube)
    subCoefficient = sizeof(coefficientFused) / numWorkers
    foreach worker i  {
      send(i, aSubCoefficient)
      finalImage = merge (finalImage, recv (i))
    }
    display(finalImage)
}
```

Program 2: Manager

```
worker(numSubImages, numWorkers) {
  aSubImage = recv (manager)
  coeffMatrix = convolve(aSubImage)
  coeffMatrix = activityMeasure(coeffMatrix)
  coeffMatrix = coeffGrouping(coeffMatrix)
  send (manager, coeffMatrix)
  subCoefficient = recv(manager)
  subImage = inverseTransform(subCoefficient)
  send (manager, subImage)
}
```

Program 3: Worker

5.1 Image evaluation

In our work, we use the SNR (signal-to-noise ratio) to evaluate the image quality. The method is widely used in remote sensing as quality measurement methods. Moreover, we also evaluate the image quality using human interpretation to assure that the measurement is not done only through the pixel differences. The signal-to-noise ratio (SNR) reflects the differences of the information content (referred to as errors) between an original image and a fused image using the average data. The SNR numbers are reported in Decibels (dB) as a measure of the relative weight between two images. A higher number in dB indicates a higher correlation. The SRS is directly proportional to the image quality.

$$SNR = 10\log \frac{\sum_i \sum_j (Bv_{orig(i,j)} - Bv_{fuse(i,j)})^2}{\sum_i \sum_j Bv_{orig(i,j)}} \quad \text{eq (7)}$$

From equation 7, i and j define the pixel coordinates, $Bv_{orig(i,j)}$ represents the pixel intensity (brightness) value of the original image, and $Bv_{fuse(i,j)}$ is the intensity of the fused image.

To demonstrate our parallel fusion model, it was applied to the Landsat Enhanced Thematic Mapper [Goward et.al. 1996] satellite data. The Landsat ETM+ sensor provides data from eight spectral bands ranges from 0.45 to 12.5 micron. The sensor is used to acquire images around the globe at discrete spectral resolution. The spatial resolutions of the data range from 15 to 60 meter, where the 30-meter resolution is for the visible and near-infrared (bands 1-5, 7). The thermal infrared (band 6) is 60 meters, and the panchromatic (band 8) is 15 meters. The approximate scene size is 183 x 170 kilometers (8900x8290 pixels). All of the multi-spectral images are arranged into a three-dimensional data structure of two spatial dimensions and one spectral dimension. The data set used in this work is radiometric-corrected images from path 131, row 47 with center of coordinate N18.79, E098.62. The acquisition date is 23 February 2002. The scene corresponds to the area in Chiangmai, Thailand, which contains a good mixture of forest, river, road, and urban area. Figure 5 shows some example images of Landsat ETM+ data. From the original data, band 3 shows the road systems, band 5 emphasizes the river and the airport strip, while band 8 and band 5 have the best contrast for the urban area.

(a) band1

(b) band2