PCT WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : G02B — A2

(11) International Publication Number: **WO 99/13360**

(43) International Publication Date: 18 March 1999 (18.03.99)

(21) International Application Number: PCT/US98/18852

(22) International Filing Date: 9 September 1998 (09.09.98)

(30) Priority Data:

08/926,795	10 September 1997 (10.09.97)	US
08/926,903	10 September 1997 (10.09.97)	US

(71) Applicant: BELLSOUTH INTELLECTUAL PROPERTY CORPORATION [US/US]; 1155 Peachtree Street, N.E., Atlanta, GA 30309–3610 (US).

(72) Inventors: MCCLELLAN, Stanley, A.; 2313 Queensview Road, Hoover, AL 35226 (US). GRIMES, Gary, J.; 5019 Trace Crossing Lane, Hoover, AL 35244 (US). FLEMING, Norman, Wayne; 3276 Farrington Wood Place, Birmingham, AL 35243 (US).

(74) Agents: LINDER, Walter, C. et al.; Faegre & Benson, 2200 Norwest Center, 90 South Seventh Street, Minneapolis, MN 55402–3901 (US).

(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, GH, GM, HR, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

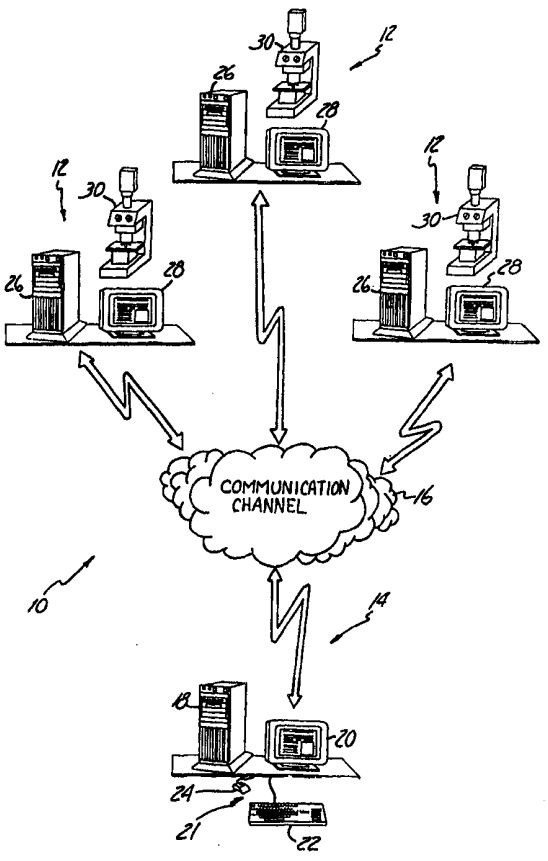
Published

Without international search report and to be republished upon receipt of that report.

(54) Title: DIGITAL TELEPATHOLOGY IMAGING SYSTEM WITH BANDWIDTH OPTIMIZATION AND VIRTUAL FOCUS CONTROL FUNCTIONS

(57) Abstract

A digital telemedicine or other remotely–controlled imaging system for enabling an operator at a local site (14) to analyze images (70) received in digital form from an auto–focus microscope located at a remote site (12). The system (10) includes a bandwidth optimization system and a virtual focus system with a graphic user interface (50). The bandwidth optimization system enables an operator to conveniently select the resolution of images to be observed, and to enhance the resolution of portions of images currently under observation. The computational burden at the remote site and transmission requirements between the sites are thereby reduced. The virtual focus system enables an operator to emulate direct and continuous control over the microscope focus. The focus system is convenient to use and enables the operator to effectively observe the specimen at a number of different focal planes.



FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	**ES**	Spain	**LS**	Lesotho	**SI**	Slovenia
AM	Armenia	**FI**	Finland	**LT**	Lithuania	**SK**	Slovakia
AT	Austria	**FR**	France	**LU**	Luxembourg	**SN**	Senegal
AU	Australia	**GA**	Gabon	**LV**	Latvia	**SZ**	Swaziland
AZ	Azerbaijan	**GB**	United Kingdom	**MC**	Monaco	**TD**	Chad
BA	Bosnia and Herzegovina	**GE**	Georgia	**MD**	Republic of Moldova	**TG**	Togo
BB	Barbados	**GH**	Ghana	**MG**	Madagascar	**TJ**	Tajikistan
BE	Belgium	**GN**	Guinea	**MK**	The former Yugoslav Republic of Macedonia	**TM**	Turkmenistan
BF	Burkina Faso	**GR**	Greece			**TR**	Turkey
BG	Bulgaria	**HU**	Hungary	**ML**	Mali	**TT**	Trinidad and Tobago
BJ	Benin	**IE**	Ireland	**MN**	Mongolia	**UA**	Ukraine
BR	Brazil	**IL**	Israel	**MR**	Mauritania	**UG**	Uganda
BY	Belarus	**IS**	Iceland	**MW**	Malawi	**US**	United States of America
CA	Canada	**IT**	Italy	**MX**	Mexico	**UZ**	Uzbekistan
CF	Central African Republic	**JP**	Japan	**NE**	Niger	**VN**	Viet Nam
CG	Congo	**KE**	Kenya	**NL**	Netherlands	**YU**	Yugoslavia
CH	Switzerland	**KG**	Kyrgyzstan	**NO**	Norway	**ZW**	Zimbabwe
CI	Côte d'Ivoire	**KP**	Democratic People's Republic of Korea	**NZ**	New Zealand		
CM	Cameroon			**PL**	Poland		
CN	China	**KR**	Republic of Korea	**PT**	Portugal		
CU	Cuba	**KZ**	Kazakstan	**RO**	Romania		
CZ	Czech Republic	**LC**	Saint Lucia	**RU**	Russian Federation		
DE	Germany	**LI**	Liechtenstein	**SD**	Sudan		
DK	Denmark	**LK**	Sri Lanka	**SE**	Sweden		
EE	Estonia	**LR**	Liberia	**SG**	Singapore		

DIGITAL TELEPATHOLOGY IMAGING SYSTEM WITH BANDWIDTH OPTIMIZATION AND VIRTUAL FOCUS CONTROL FUNCTIONS

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates generally to remotely-controlled imaging systems. In particular, the present invention is a remotely-controlled microscope imaging system for telepathology having programmed bandwidth optimization and virtual focus control functions.

Description of the Related Art

Pathologists routinely assist surgeons by analyzing and providing diagnostic opinions on frozen sections of tissue samples removed from patients during surgery. Frozen sections are small tissue specimens which are quick-frozen, sliced, treated with dyes and placed on slides. The slides are then analyzed through a microscope by the pathologists. The diagnoses provided by the pathologists are used by the surgeons in the course of determining the nature and extent of further surgical procedures. For example, pathologists often analyze tissue samples to determine whether they are cancerous, and to determine the type of cancer present. Using this information the surgeon will determine which tissue should be removed from the patient.

A typical turnaround time for preparing a frozen section is about fifteen minutes. During the tissue sample analysis session a pathologist will typically first rapidly scan the entire sample for gross features at a relatively low magnification, and identify particular sample regions of interest for more detailed study. The selected regions of interest are then observed at relatively high magnifications. It is typical for a pathologist to observe many separate regions at a number of different magnifications during an analysis session. The length of time required by the pathologist to complete this procedure and provide a diagnosis often about five to seven minutes.

During diagnostic sessions pathologists will often observe a given specimen region at a number of different focal planes. The need for these range of focus observations is due at least in part to the fact that the specimen being imaged has depth

(i.e., is three-dimensional). Portions of the specimens at different depths must therefore be imaged at different focal planes.

Large hospitals and universities often maintain an on-site clinical pathology laboratory and staff of pathologists to provide these services on demand. Since the diagnoses can be used to guide procedures to completion during a single surgery, the immediate access to the pathologist's expertise during surgery can provide significant benefits in terms of both economic and recuperative aspects of healthcare delivery.

Smaller and outlying hospitals often rely on periodic visits from "circuit-riding" pathologists that provide scheduled service to a group of hospitals. This commuting arrangement can be inefficient, since certain types of surgeries must be scheduled to coincide with the pathologist's visit. Travel time can also be an inefficient use of the pathologist's time. Furthermore, if routine or emergency surgical procedures being performed when the pathologist is not scheduled suddenly require a pathologist's expertise, the tissue sample must be shipped to a remote laboratory for diagnosis. The patient may then have to undergo surgery yet another time after the pathological diagnosis has been completed. These procedures can result in increased costs and reduced effectiveness of healthcare delivery.

A known solution to the problems associated with the lack of timely on-site access to the expertise of pathologists and other medical personnel is the application of telecommunications technology, also known as telemedicine. Telepathology imaging systems, a type of remotely-controlled imaging systems which use communication technology to enable the remote observation of medical specimens, are known, and generally fall into one of two categories. So-called static telepathology systems make use of a trained pathologist and a laboratory having a microscope with digital electronic imaging capabilities. Systems of this type are disclosed generally in the Weinstein et al. article *Telepathology: Long-Distance Diagnosis*, American Journal of Clinical Pathology, Vol. 91, pp. S39 - S42, 1989. A clinician or other "sender" prepares the frozen sample tissue specimen, analyzes the specimen through the microscope, and identifies a number of specimen regions that appear to be of interest. Digital images of the selected regions of interest are then generated, and electronically transferred to another site for analysis and

diagnosis by a pathologist. The pathologist can also communicate with the sender (e.g., by telephone) during these procedures, and request images of specific sample regions.

Dynamic systems such as those disclosed in the Weinstein et al. U.S. Patent 5,216,596 make use of a trained clinician and a laboratory having a microscope with a conventional analog video camera. "Live" images of the specimen sample produced by the video camera are transmitted to a television monitor using conventional NTSC or PAL analog video signal protocols, or compressed and transmitted using well-known digital video conferencing technologies for transmission to remote sites.

Since the operator has remote control over the microscope focus function in systems such as those disclosed in the Weinstein et al. patent, he or she can observe a number of different focal planes of the remotely-located specimen. Other remotely-controlled microscope systems, however, such as that described in the above-identified related application entitled "Digital Telepathology Imaging System" make use of conventional automatic focus systems on the remote microscope. Each time a new image region is imaged, or the magnification changed, the automatic focus system is actuated to focus the microscope. Digital data representative of a still image is then transmitted to the pathologist for observation. Since systems of this type do not provide pathologists with direct access to the focal plane adjustment of the microscope, the pathologists are unable to remotely observe different focal planes of the image.

Known technology for image and video transmission and virtual environment rendering typically allocates computational and transmission resources which vary based on image content, interframe motion or scene complexity. Generally, the delivery of imagery with detailed content requires more encoding volume or computational effort (i.e., bandwidth) than imagery which has little detail or has predominately lowpass characteristics.

For the transmission of discretized real-world imagery, the conventional (e.g., open-loop or machine-based) approach to determining which portions of an image sequence require extra bandwidth relies on a decomposition or blockwise analysis of the image sequence at the transmitter. Transmission and computational resources are thereby expended to decompose and prioritize an image sequence in terms of frequency

content (equivalently, correlation) and/or motion of image content between consecutive frames.

During the use of remotely-controlled imaging systems, certain portions of an image under observation may be of higher interest than others. In telepathology, for example, if an area of a transmitted image has a dominant color such as blue, it is more likely to be an area of malignancy and therefore of greater interest to a pathologist than other (e.g., non-blue) portions of the image. Applications of this type generally demand lossless transmission, high spatial precision or color-space accuracy and relatively large computational resources. However, the prioritization of image data by conventional methods for encoding and transmission are generally not appropriate under these circumstances.

It is evident that there is a need for improved remotely controlled imaging systems. In particular, there is a need for improved bandwidth prioritization systems for telepathology and other remotely controlled imaging systems. There also is a need for a mechanism by which an operator can obtain images at a number of different discrete focal planes from a microscope or other imaging instrument at a remote location. It would be especially advantageous if such a remote focusing system were able to emulate conventional direct control over the focal plane. To be commercially viable and efficacious, the systems must be cost-effective and enable timely, high-quality healthcare delivery. A telemedicine imaging system providing these benefits should be capable of generating diagnostic-quality images while enabling real-time image selection control. The system should also make efficient utilization of communication channel and computational resources while using lossless image transfer protocols.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a diagrammatic illustration of a telepathology imaging system which includes bandwidth optimization and virtual focus systems in accordance with the present invention.

Figure 2 is an detailed diagrammatic illustration of one of the server systems shown in Figure 1.

Figure 3 is an illustration of the graphic user interface (GUI) menu generated and displayed by the client system shown in Figure 1.

Figure 4 is an illustration of a GUI Open Session menu.

Figure 5 is an illustration of a tiled slide overview specimen image.

Figure 6 is an illustration of several cascaded specimen images with the GUI microscope control menu and zoom factor menu on the top image.

Figure 7 is an illustration of several cascaded specimen images with the GUI image region selection reticle on the top image.

Figure 8 is an illustration of GUI microscope control and resolution menus generated and displayed by the client system shown in Figure 1.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

System Architecture and Overview

A "virtual microscope" imaging system 10 for telepathology (i.e., a remotely-controlled imaging system) which includes bandwidth optimization and virtual focus systems in accordance with the present invention can be described generally with reference to Figure 1. As shown, system 10 includes one or more (three are shown) "server" systems 12 which are interfaced to a "client" system 14 over a digital telecommunication channel 16. Client system 14 is located at a hospital or other local site of a pathologist, and includes a workstation 18, monitor 20 and operator-actuated user input 21 such as keyboard 22 and/or mouse 24. Each server system 12 will typically be located at a hospital or other remote surgical site which does not have a staff pathologist, and includes a workstation 26, monitor 28, microscope station 30 and keyboard or other user input (not shown). During surgical procedures being performed at the remote site of a server system 12, a technician or other clinician will prepare slides of frozen sample or other tissue specimens and position the specimen slides on microscope station 30. A pathologist or other clinician at the local site of client system 14 remotely controls the operation of the server system 12 through the use a graphical user interface (GUI) displayed on monitor 20 and the operator-actuated user input 21. In response to digital server system control commands received from the client system 14 over the

communication channel 16, digital still images of the specimen are generated by the microscope station 30, transmitted to the client system and displayed in diagnostic-quality form on the monitor 20. The pathologist can, for example, observe an image of the entire specimen at a relatively low magnification, and identify particular specimen regions for more detailed analysis at greater magnification levels. Server system control commands such as specimen region commands designating the selected specimen regions, magnification commands designating the desired magnification and illumination commands for controlling specimen illumination and imaging parameters of the camera are then generated by the client system 14 and transmitted to the server system 12 over the communication channel 16. Server system 12 processes the control commands, manipulates the specimen illumination and camera parameters, and transmits to the client system 14 specimen image data for the selected specimen region at the desired magnification.

Communication channel 16 will typically be a broad bandwidth public network communication link capable of supporting packet-switched data communications. For example, ISDN (integrated services digital network) or T1 telephone lines can be used. Conventional and commercially available digital switching systems (not shown) can be used to interface server system 12 and client system 14 to the communication channel 16. Prototypes of system 10 were developed using an ATM-based (asynchronous transfer mode) optical channel 16 and an Ethernet network.

A representative server system 12 can be described in greater detail with reference to Figure 2. Microscope station 30 is a conventional and commercially available instrument which includes a microscope 31 and a stage 34 for receiving and supporting specimen slides (not separately shown) to be imaged by lenses or objectives 36. The stage 34 is mounted to the base of the microscope 31 by an x-y stage drive 40 so the position of the slide with respect to the objectives 36, and therefore the region of the specimen being imaged, can be changed. The microscope 31 includes several objectives 36, each of which provides a different magnification power. Focusing is performed by a conventional automatic focus control system (not separately shown). The objectives 36 are driven and positioned by a drive 38 to change the magnification of the microscope.

Although not shown, the microscope 31 also includes a conventional slide illumination light source and actuator-driven neutral density filter for controlling the specimen illumination level.

A high-resolution camera 42 generates true-color image data representative of the specimen images produced by the microscope. This image data is digitized by the workstation 26. The camera 42 and digitizing system in workstation 26 function as a digital imaging system. Prototypes of system 10 include a camera 42 having a base resolution of at least approximately 600 x 800 pixels, and a digitizing system capable of capturing 8-bit per pixel (bpp) per color band still images (for a total of 24 bpp color). Conventional imaging control parameters of camera 42 can be accessed and controlled.

Microscope station 30 is interconnected to workstation 26 through one or more interfaces illustrated generally at 44. Prototypes of system 10, for example, include an analog interface for connecting camera 42 to the workstation 26 and its digitizing system, and RS-232 busses for interconnecting the stage drive 40, objective drive 38, automatic focus system and image illumination system to the workstation 26. Monitor 28 is interconnected to workstation 26 by bus 46. These systems are capable of acquiring a still image and displaying that image at full resolution on the monitor 28 in less than about 1 second.

Workstation 26 is a conventional programmable computer, and is programmed with server system control software to control the operation of microscope station 30 in response to digital server system control commands received from the client system 14. Control commands received from server system 14 include camera commands, specimen region commands, magnification commands, focus commands and illumination commands. The specimen region commands include information designating a specific or desired region of interest on the specimen slide, and in one embodiment include information designating coordinates on the specimen slide in terms of "stage units." In response to the receipt of specimen region commands, workstation 26 actuates stage drive 40 and moves stage 34 to position the selected region of the specimen slide under objective 36. The magnification commands include information designating the desired magnification at which the selected specimen region is to be imaged. In response to the

receipt of magnification commands, workstation 26 actuates drive 38 and causes the selected objective 36 to be used to image the specimen region. In response to camera commands, camera 42 generates specimen image data representative of a still image of the specimen region being imaged by the microscope 31. As described above, this image data is digitized by the workstation 26.

As noted above, microscope 31 includes automatic focus and specimen slide illumination control systems. In response to focus commands received from client system 14, workstation 26 initiates an automatic focus routine by the automatic focus system of the microscope 31. Workstation 26 also initiates an automatic focus routine each time the magnification is changed. Workstation 26 also controls the illumination system of the microscope 31 (e.g., the neutral density filter) to change the illumination level of the specimen slide in response to illumination commands received from the client system 14, and can vary the imaging parameters of camera 42.

Prototypes of system 10 use conventional TCP/IP protocol (transport control protocol/internet protocol) for the transfer of the server system control commands and specimen image data. The TCP/IP protocol of the prototype system 10 is supported by the Windows Sockets application programming interface (API) which provides handshaking, error reporting and associated functions, and is therefore compatible with local area network (LAN) as well as LAN-over-broadband telecommunications architectures.

Client system 14 can include a workstation 18 and monitor 20 similar to those of server system 12. Workstation 18 is programmed with client system control software and GUI software. The GUI software generates and displays a Windows™-format GUI on monitor 20. Through the use of the GUI and user input 21, the pathologist or other clinician can select the specimen regions to be imaged by the microscope station 30 of a server system 12, and the desired magnification of the selected specimen region. Server system control commands, including the specimen region commands and magnification commands designating the image selected by the pathologist, are generated by the client system control software and transmitted to the server system 12 over communication channel 16. The client system control software also processes the digital image data

received from the server system 12, and generates visual displays on monitor 20 of the associated specimen images represented by the data.

Graphic User Interface And System Operation

Figure 3 is an illustration of the GUI menu 50 generated by workstation 18 and displayed on monitor 20 at client system 14. The illustrated embodiment of menu 50 includes a menu bar 52 and a toolbar 54. The pathologist operates system 10 by using keyboard 22 and/or mouse 24 in a conventional manner to select commands on menu bar 52 and toolbar 54. As described below, other commands not graphically displayed on the GUI can be selected by clicking the left and right buttons (not separately shown) of the mouse 24. In addition to conventional Windows™ commands (e.g., Window and Help), menu bar 52 includes the system-specific commands System, Session and Microscope. Toolbar 54 includes a number of conventional Windows™ command buttons 55 - 58, microscope (e.g., stage drive) control buttons 59, and a new slide button 60. Buttons 55 and 56 are format buttons for selecting tiled or cascaded specimen image displays, respectively. Arrange icon button 57 and information button 58 provide conventional Windows™ functions when selected. Get slide button 60 can be actuated by the pathologist to obtain a tiled slide overview image (described in greater detail below) when a new specimen slide has been positioned for imaging on the remote microscope station 30. The tiled slide overview image can also be initiated by the technician at the server system 12. A listing of the commands and associated functions available through the selection of the System, Session, Microscope, Window and Help commands on menu bar 52 follows. Many of the commands provide conventional Windows™-format functions, and are identified as "Standard" in the listing.

Menu Bar Options

System

Preferences	Display "user preference" options to set parameters such as the way new images are displayed, the width of reticle borders, the way that gamma

	correction is performed, and the server sites that are available
Save	Standard
Save As	Standard
Print	Standard
Print Setup	Standard
Exit	Standard

Session

Connect	Establish diagnostic session with server system (remote microscope) site
Gamma Correction	Perform gamma correction on an existing image according to settings in "Preferences" menu
Get Slide	Retrieve overview of entire specimen
Remote Database	Establish session with existing remote database (as opposed to remote control of a microscope)
Chat	Establish TCP/IP "chat" session with remote node to interact with remote user via keyboard
Submit Diagnosis	Display form for pathologist to complete with info specific to this diagnostic session, including fields for diagnosis, confidence level, system performance, image quality, etc. then send completed form to microscope location to be included with "trajectory" and patient history. This option finalizes the session
Patient Information	Display summary information retrieved from electronic patient record or entered by technician at microscope site

Microscope

Refocus	Instruct remote microscope to perform autofocus routine (automatically retrieves another image)
Intensity	Instruct remote microscope to change illumination of specimen via neutral density filter and/or camera parameters
Get Image	Retrieve another copy of the current image from remote microscope
Image	Perform interactive adjustment of image brightness to remotely calibrate the

Calibrate	microscope's camera settings

Window

Tile	Standard
Cascade	Standard
Arrange All	Standard
About	Standard

Help

Contents	Standard
Search for Help	Standard
How to Use Help	Standard

Figure 4 is an illustration of a GUI open session menu displayed on monitor 20 and used by the pathologist to initiate a remote specimen observation session. The open session menu will be presented to the pathologist upon the selection of the Connect command available through menu bar 52. As shown, the open session menu includes a list of server systems 12 set up for operation with the client system 14, and displays the then-current specimen slide illumination (intensity) and image magnification (the established "user preference" values). Workstation 18 initiates and establishes an operational communication interface with the server system 12 selected by the pathologist through the open session menu.

The pathologist will typically begin the diagnosis of a specimen by observing a slide overview image 70 such as that shown in Figure 5. The slide overview image 70 is a relatively low magnification image of a relatively large portion of the specimen on the slide, and in one embodiment is an image of the entire specimen on the slide. In the embodiment shown, the slide overview image 70 is an assembly of separate and discrete specimen region images 72 into a tiled overview image of the entire specimen on the slide. The slide overview image 70 shown in Figure 5, for example, is formed from a 3 x 4 array of specimen region images 72.

Generation of the overview image 70 is controlled by the server system control software in workstation 26. In response to Get Slide commands (or Send Slide commands initiated by the clinician at server system 12), the workstation 26 actuates objective drive 38 to select a relatively low magnification (e.g., 2x) objective 36 and initiates an automatic focus routine. Stage drive 40 and camera 42 are then actuated to sequentially obtain the adjacent specimen region images 72. The image data for the specimen region images 72 is processed by the server system to reduce the resolution of the images, and transmitted to the client system 14 where it is assembled and displayed as the slide overview image 70. The image data for each of the specimen region images 72 can be cached in memory of the workstation 18 so the image can be redisplayed as the topmost image on monitor 20.

As noted above, the generation of a slide overview image 70 can be initiated at either the server system 12 or the client system 14. After positioning a new specimen slide on microscope station 30, the clinician can, for example, initiate the generation of a slide overview image 70 by selecting a Send Slide command through a graphic user interface and user input (not separately shown) at the server system 12. Image data representative of the slide overview image 70 will then be transmitted to the client system 14 and displayed on monitor 20, thereby indicating to the pathologist the availability of the specimen slide for observation. If the image data has already been transmitted by the server system 12, the pathologist can also initiate the generation of a new slide overview image 70 from the client system through use of the Get Slide command button 60 on toolbar 54 or the Get Slide command available through menu bar 52.

During observation of the slide overview image 70 the pathologist will typically identify specimen regions that he or she would like to observe in greater detail. Using the GUI and user input 21, the pathologist can select the specimen region of interest and the desired magnification at which the specimen region is to be observed. The appropriate server system control commands are then generated by the client system control software and transmitted to the server system 12 to initiate the retrieval and display of the specimen region of interest image (i.e., a detail image).

Specimen regions of interest can, for example, be selected by positioning the GUI cursor over the image and clicking the right button on mouse 24. As shown in Figure 6, this command causes a GUI microscope control menu 80 to be generated and displayed on monitor 20. Available commands in the microscope control menu 80 include Zoom and Zoom Factor. When the Zoom command is selected through user input 21, the GUI software generates and displays on the then-displayed specimen region image an indicator such as reticle 82 shown in Figure 7. Using the user input 21 the pathologist can then reposition the reticle 82 over the specimen region of interest on the image, and thereby select the specimen region for further observation. Returning to the microscope control menu 80, the pathologist can then select the Zoom Factor command and cause the zoom factor menu 84 (Figure 6) to be generated and displayed by the GUI software. The zoom factor menu 84 includes a number of discrete magnification level commands corresponding to the available magnification levels (e.g., objectives 36) on microscope station 30, as well as In and Out step commands. The In command causes the magnification to increase one available power level from the then-current magnification at the microscope station 30, while the Out command causes the magnification to decrease one available power level from the then-current magnification. By clicking the left button of mouse 24 after selecting the desired magnification and image region of interest in the manner described above, the pathologist will initiate the generation and transmission of the appropriate magnification and specimen region commands to retrieve the image.

Using the client system 14 in the manner described above, the pathologist is able to relatively quickly observe images of many different specimen regions at different magnifications. As is evident from Figure 6, multiple images can be simultaneously displayed on monitor 20. The images can be displayed in a manner which enables the pathologist to easily identify the location of the specimen region image with respect to the image overview and with respect to all other images. The magnification of the image is also displayed. Workstation 26 automatically maintains a log or cache describing in chronological sequence the control commands transmitted to the server system 12 and the coordinates of the specimen region of the retrieved image. In addition to providing an audit trail, this information streamlines the image acquisition and transfer functions and

provides the pathologist with immediate feedback regarding the regions of the specimen which have been imaged. Each of the retrieved specimen images can be stored by the workstation 26 for subsequent retrieval and observation.

System 10 offers a number of important advantages, especially with respect to known "static" and "dynamic" architectures. High-resolution, diagnostic-quality, color images can be retrieved and displayed in real time. The system can be efficiently operated through the user-friendly graphic user interface. Commercially available hardware can be used to implement the system. The network protocol is also robust, scalable (works on many different size channels), fast and relatively secure. The system allows pathologists to quickly provide high-quality diagnostic opinions to multiple remote locations, thereby making efficient use of their time. Accurate, precise, real-time control of the remote imaging system is achieved. The system can be integrated with electronic patient record systems to include patient information and diagnostic results. The audit trails which can be provided are also advantageous.

Virtual Focus Function

Imaging system 10 can be configured to include a focal plane adjustment system which effectively provides a virtual focus capability to the pathologist at client system 14. The virtual focus function allows the pathologist to sequentially display on monitor 20 a series of different and discrete specimen region images, all of which are images of the same specimen region and at the same magnification, but which are taken at a range of focal planes on opposite sides of the "in-focus" focal plane to which the objective 36 is driven by the automatic focus system of the microscope 31. The speed at which the different focal plane specimen region images are presented on monitor 20 can be controlled by the pathologist through the use of the GUI and/or user input 21 to simulate the observation of the specimen image under conventional manual focus control.

The virtual focus function of system 10 can be selected by the pathologist through the use of the GUI and/or user interface 21. One embodiment, for example, includes a Dynamic Focus command in the list of commands available under the Microscope command on menu bar 52. In response to pathologist selection of the Dynamic Focus

command, workstation 18 generates and transmits to server system 12 a focus adjust command. Generation of the different focal plane specimen region images is controlled by the server system control software in workstation 26. In response to the receipt of the focus adjust command, workstation 26 actuates the automatic focus system of the microscope 31 and camera 42 to generate image data for several specimen region images taken at a range of different focal planes on both sides of the in-focus focal plane determined by the automatic focus system of the microscope 31. In one embodiment, for example, workstation 26 initiates the generation of three specimen region images at three different focal planes below the in-focus focal plane, a specimen image at the in-focus focal plane, and three specimen region images at three different focal planes above the in-focus focal plane. The selected "out-of-focus" focal planes are typically symmetrically located about the in-focus focal plane. The image data for the virtual focus specimen images is then transmitted to the client system 14.

Upon receipt of the virtual focus specimen image data, the client system 14 will initially cause one of the images (typically the in-focus image) to be displayed on monitor 20. The GUI presented with the virtual focus images will also include a focus control element which can be selected or actuated by the pathologist through the use of user interface 21. In one embodiment, for example, the GUI will include a conventional Window™-type slider bar on an edge of the display (not shown). Using the mouse 24 the pathologist can click on the arrows (also not shown) at the opposite sides of the slider bar, or click and drag on the slider button, to cause specimen region images at "adjacent" focal planes to be sequentially displayed on the monitor 20.

During diagnostic sessions pathologists will routinely observe a given specimen region at a number of different focal planes. The reason for these range of focus observations is due at least in part to the fact that the specimen being imaged has depth (i.e., is three-dimensional). Portions of the specimen at different depths must therefore be imaged at different focal planes. The virtual focus function of system 10 allows the system to closely emulate the manner by which a pathologist would analyze a specimen through the direct use of a conventional microscope.

Bandwidth Optimization Function

System 10 also offers the pathologist the capability of selecting the fidelity of the specimen region images generated by server system 12 and transmitted to the client system 14 over communication channel 16. In one embodiment, for example, and as shown in Figure 8, the GUI microscope control menu 80 generated and displayed on monitor 20 when the pathologist is selecting specimen regions of interest includes a Resolution command. When the Resolution command is selected through the use of the user input 21, a resolution menu 90 is generated and displayed on the monitor 20 by the GUI software. The resolution menu 90 includes a number of discrete resolution level commands corresponding to the available resolution levels (e.g., bits per pixel for a full color image), as well as Better and Worse step commands. The Better command causes the resolution to increase one available level from the then-current resolution, while the Worse command causes the resolution to decrease one available level from the then-current resolution. By clicking the left button of mouse 24 after selecting the desired resolution, the pathologist will initiate the generation and transmission of the appropriate resolution commands to the server station 12. In response, the control software at the server station 12 controls the operation of workstation 26 in such a manner that the specimen image is incrementally transmitted until the selected resolution is attained.

The capability of controlling the resolution of the specimen images generated and transmitted by the server system 12 provides important advantages. Images of specimen regions of particular interest to the pathologist can be generated and transmitted at relatively high fidelity (i.e., relatively low spatial and/or color space distortion). Lossless and high fidelity images of this type will enable the pathologist to provide accurate diagnostic opinions. Images of regions of lower priority, on the other hand, can be generated and transmitted at lower fidelity levels which require less bandwidth from the communication channel 16. Lower fidelity images can therefore be generated, transmitted and displayed with greater speed and efficiency, enhancing the overall efficiency and usefulness of the system 10.

Additionally, if low-fidelity images have been transmitted and contain subregions which are of particular interest to the pathologist, the image information which is desired

for diagnostic confidence can be transmitted incrementally, for that subregion only. For example, the pathologist can be observing a full-screen, relatively low resolution image transmitted to client system 14 (e.g., through use of a Zoom command). If the image is largely uninteresting, but a relatively small subregion which could be important is identified, the pathologist can select the Resolution command in the manner described above. In response to the selection of the Resolution command, the GUI software generates and displays a resolution indicator such as a resolution reticle (not shown), which can be similar to the reticle 82 described above with respect to the Zoom command. The resolution reticle or other indicator can be positioned over the image subregion of interest using the GUI and user input 21 in a manner similar to that described above for manipulating Zoom command reticle 82.

After the resolution reticle is positioned, the pathologist clicks the left button on mouse 24 to initiate the generation and transmission of a resolution command to the server system 12. The server system 12 has already generated the digital image data at full resolution (e.g., 24 bpp) for the entire image region being displayed at relatively low resolution on monitor 20, and "degraded" this image data to produce the previously transmitted relatively low resolution version. Server system 12 also includes a stored record identifying the image data previously transmitted for the relatively low resolution image. The server system 12 therefore transmits only the additional image data required to augment the already-transmitted image subregion with an incremental improvement to obtain the desired resolution. These Resolution command procedures can be repeated on the same (or overlapping) image subregions until the "incremental" image data transmissions have completed the total available resolution (e.g., 24 bpp) for the selected image subregion. When used in this manner, the Resolution command effectively provides a function similar to the Zoom command.

Although the present invention has been described with reference to preferred embodiments, those skilled in the art will recognize that changes can be made in form and detail without departing from the spirit and scope of the invention. In particular, although described as a telepathology system, the invention can be used in other remotely-controlled microscope applications.

WHAT IS CLAIMED IS:

1. A digital imaging system for enabling a person at a local site to observe and analyze images received in digital form from remote site, comprising:

a server system at the remote site, including:

image data means for providing digital image data representative of images; and

a workstation interconnected to the image data means and including:

a communication channel interface port adapted to be interfaced to a digital data communication channel over which the digital image data and server system control commands are transmitted between the local and remote sites; and

image output means responsive to resolution commands for outputting the digital image data representative of images at selected resolutions; and

a client system at the local site, including:

a monitor;

an operator-actuated user interface; and

a workstation interconnected to the monitor and operator-actuated user interface and including:

a communication channel interface port adapted to be interfaced to a digital data communication channel;

image display means responsive to the digital image data received from the server system, for causing the monitor to visually display the images; and

resolution command generation means for generating resolution commands, representative of the resolution of the digital image data to be transmitted to the client system by the server system, selected by the operator through use of the user interface.

2. The digital imaging system of claim 1 wherein the image data means of the server system workstation includes memory for storing digital image data representative of the images.

3. The digital imaging system of claim 2 wherein:

the memory for storing digital image data representative of the images stores image data at a first resolution; and

the resolution command generation means generates resolution commands, representative of the first resolution and at least a second resolution which is less than the first resolution, selected by the operator through use of the user interface.

4. The digital imaging system of claim 1 wherein the workstation further includes graphic user interface display means for causing the monitor to display a graphic user interface enabling a person using the operator-actuated interface to control the server system , including selecting the resolution of the digital image data to be transmitted.

5. The digital imaging system of claim 4 wherein:

the graphic user interface display means of the workstation further includes means for causing the monitor to display a graphic user interface enabling an operator using the operator-actuated user interface to select a specimen region of interest; and

the resolution command generation means includes means for generating commands representative of the specimen region of interest and resolution of the digital image data selected by the operator through use of the graphic user interface display and the operator-actuated user interface.

6. The digital imaging system of claim 4 wherein:

the graphic user interface display means of the client system workstation further includes means for causing the monitor to display a resolution menu in

response to clinician selection of a resolution command through use of the operator-actuated user interface; and

the resolution command generation means of the client system workstation includes means for generating resolution commands in response to clinician selection of a desired resolution from the resolution menu through use of the operator-actuated user interface.

7. The telemedicine imaging system of claim 6 wherein the resolution menu includes a list of resolution level commands representative of image data resolutions available from the server system.

8. The telemedicine imaging system of claim 7 wherein the resolution menu includes step resolution level commands representative of resolution increases and decreases to a next available resolution.

9. The telemedicine imaging system of claim 4 wherein:

the graphic user interface display means of the client system workstation includes means for causing the monitor to display a resolution region indicator on the specimen image in response to clinician selection of a resolution indicator command through use of the operator-actuated user interface, and wherein the indicator can be manipulated by the clinician through use of the operator-actuated user interface to designate a region of the image for a resolution change;

the command generation means of the client system workstation includes means for generating resolution commands representative of the selected specimen image resolution for the designated region of the image; and

the workstation of the server system includes resolution control means for causing the specimen image data outputted by the image output means to be representative of the selected specimen image resolution for the designated region of the image.

10. The digital imaging system of claim 1 wherein:

the server system further includes an imaging instrument having a focus system, for imaging an object;

the image data means of the server system includes a digital imaging system for providing digital image data representative of the images produced by the imaging instrument;

the workstation of the server system is interconnected to the focus system and digital imaging system, and further includes focus system control means, responsive to dynamic focus commands, for controlling the focus system and causing the imaging instrument to image the object at a plurality of focal planes, wherein the image output means outputs digital image data representative of the focal plane images produced by the instrument;

the image display means of the client system workstation causes the monitor to visually display the plurality of focal plane images; and

the client system workstation further includes dynamic focus command generation means for generating dynamic focus commands in response to actuation of the user interface.

11. The digital imaging system of claim 10 wherein the focus control means of the server system workstation causes the instrument focus system to image the object at an in-focus plane, at least one focal plane on a first side of the in-focus focal plane, and at least one focal plane on a second side of the in-focus focal plane, in response to the dynamic focus commands.

12. The digital imaging system of claim 11 wherein the client system workstation further includes graphic user interface display means for causing the monitor to display a graphic user interface enabling a person using the operator-actuated user interface to select focal plane images for display.

13. A remotely-controlled digital imaging system for enabling an operator at a local site to observe images produced by an instrument at a remote site, including:

a server system at a remote site, including:

an imaging instrument having a focus system, for imaging an object;

a digital imaging system for providing digital image data representative of the images produced by the imaging instrument; and

a workstation interconnected to the focus system and digital imaging system, and having a communication channel interface port adapted to be interfaced to a digital data communication channel over which the digital image data and server system control commands, including dynamic focus commands, are transmitted between the local and remote sites, the workstation including:

focus system control means, responsive to dynamic focus commands, for controlling the focus system and causing the imaging instrument to image the object at a plurality of focal planes; and

image output means for outputting digital image data representative of the focal plane images produced by the instrument at the plurality of focal planes; and

a client system at a local site, including:

a monitor;

an operator-actuated user interface; and

a workstation interconnected to the monitor and operator-actuated user interface, and having a communication channel interface port adapted to be interfaced to the digital data communication channel, the workstation including:

image display means responsive to the digital image data received from the server system, for causing the monitor to visually display the plurality of focal plane object images; and

dynamic focus command generation means for generating dynamic focus commands in response to actuation of the user interface.

14. The digital imaging system of claim 13 wherein the focus system control means of the server system workstation causes the instrument focus system to image the object at an in-focus focal plane, at least one focal plane on a first side of the in-focus focal plane, and at least one focal plane on a second side of the in-focus focal plane, in response to the dynamic focus commands.

15. The digital imaging system of claim 14 wherein the client system workstation further includes dynamic focus display control means responsive to the operator-actuated user interface, for causing the monitor to visually display the plurality of focal plane images in response to actuation of the user interface.

16. The digital imaging system of claim 15 wherein the dynamic focus display control means includes graphic user interface display means for causing the monitor to display a graphic user interface enabling a person using the operator-actuated user interface to select focal plane images for display.

17. The digital imaging system of claim 16 wherein the graphic user interface display means includes means for causing the monitor to display a graphic user interface enabling a person using the operator-actuated user interface to sequentially display the focal plane images.

18. The digital imaging system of claim 17 wherein the graphic user interface display means includes means for causing the monitor to display a slider bar enabling a person using the operator-actuated user interface to sequentially display the focal plane images.

19. The digital imaging system of claim 17 wherein the focus system of the imaging instrument includes an automatic focus control system.

20. The digital imaging system of claim 19 wherein the imaging instrument includes a microscope.

21. The digital imaging system of claim 13 wherein the client system workstation further includes graphic user interface display means for causing the monitor to display a graphic user interface enabling a person using the operator-actuated user interface to select focal plane images for display.

22. The digital imaging system of claim 21 wherein the graphic user interface display means includes means for causing the monitor to display a graphic user interface enabling a person using the operator-actuated user interface to sequentially display the focal plane images.

23. The digital imaging system of claim 13 wherein:

the client system workstation further includes graphic user interface display means for causing the monitor to display a menu having a dynamic focus command; and

the dynamic focus command generation means includes means for generating dynamic focus commands in response to selection of the dynamic focus command from the menu through use of the user interface.

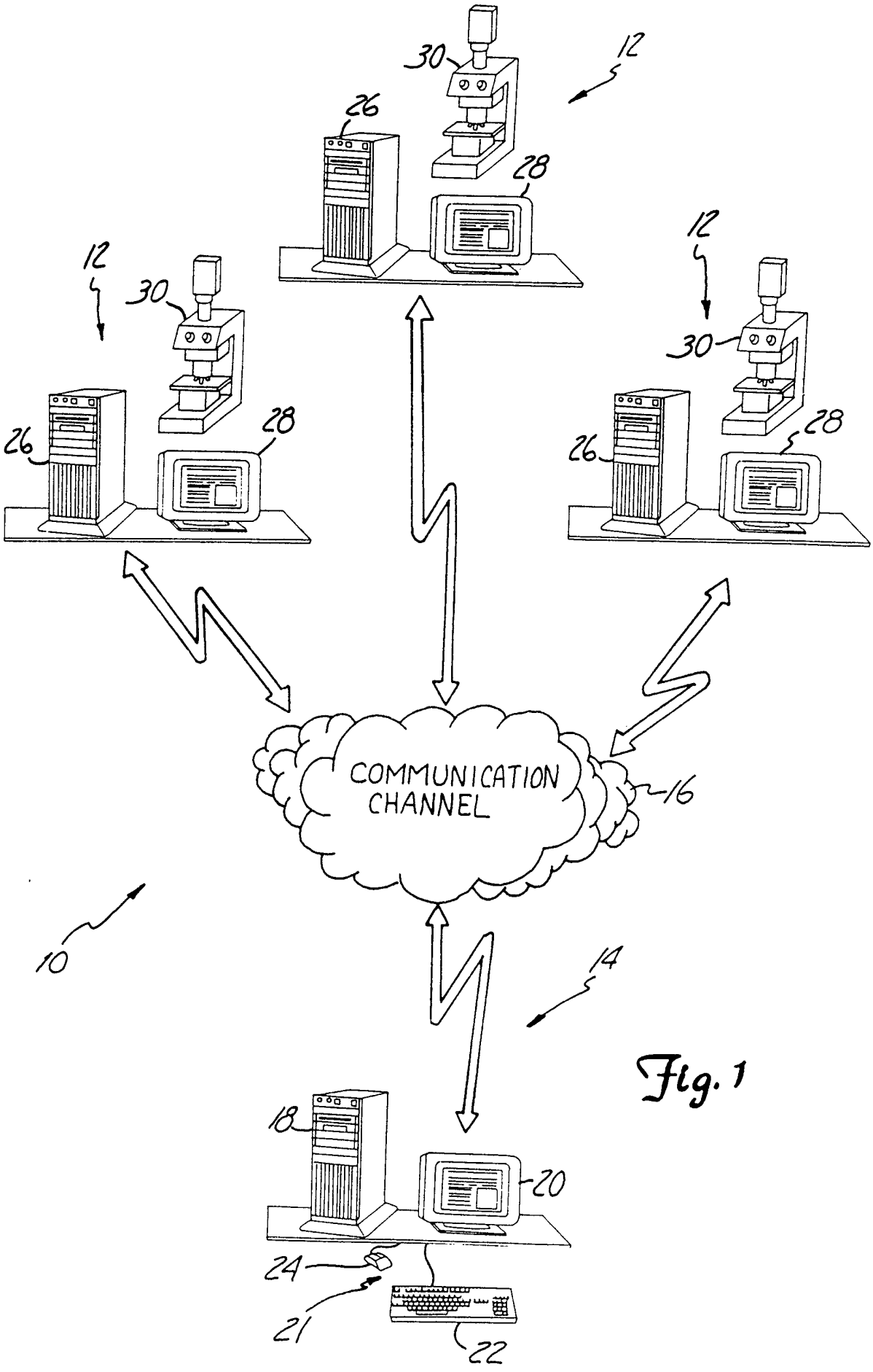

12
30
26
28
12
30
26
28
12
30
26
28
COMMUNICATION CHANNEL
16
10
14
18
20
24
21
22

Fig. 1

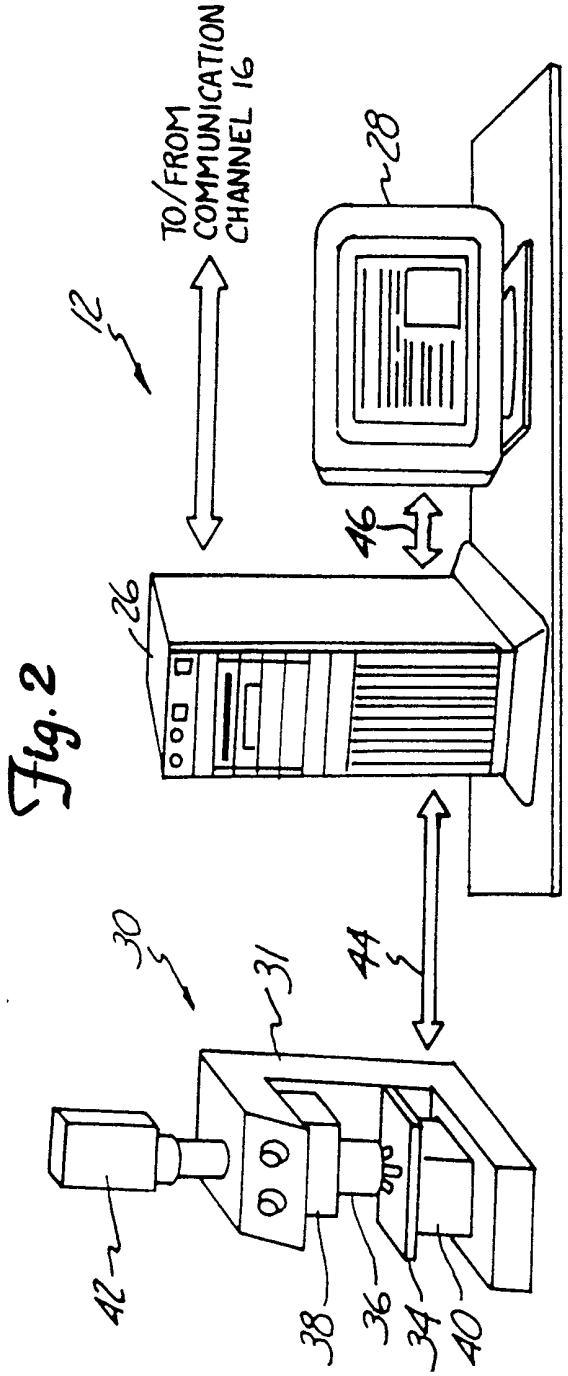

TO/FROM COMMUNICATION CHANNEL 16
12
28
46
26
30
31
44
42
38
36
34
40

Fig. 2

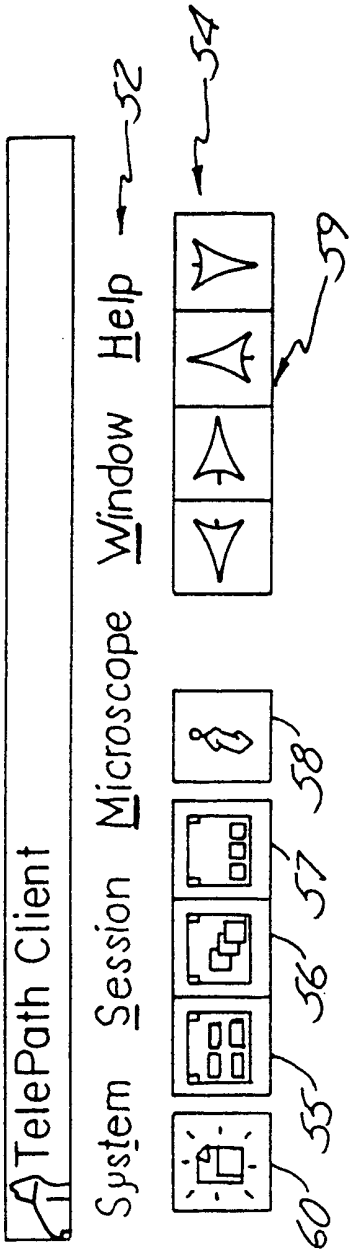

50
TelePath Client
System Session Microscope Window Help
52
54
59
60
55
56
57
58

Fig. 3

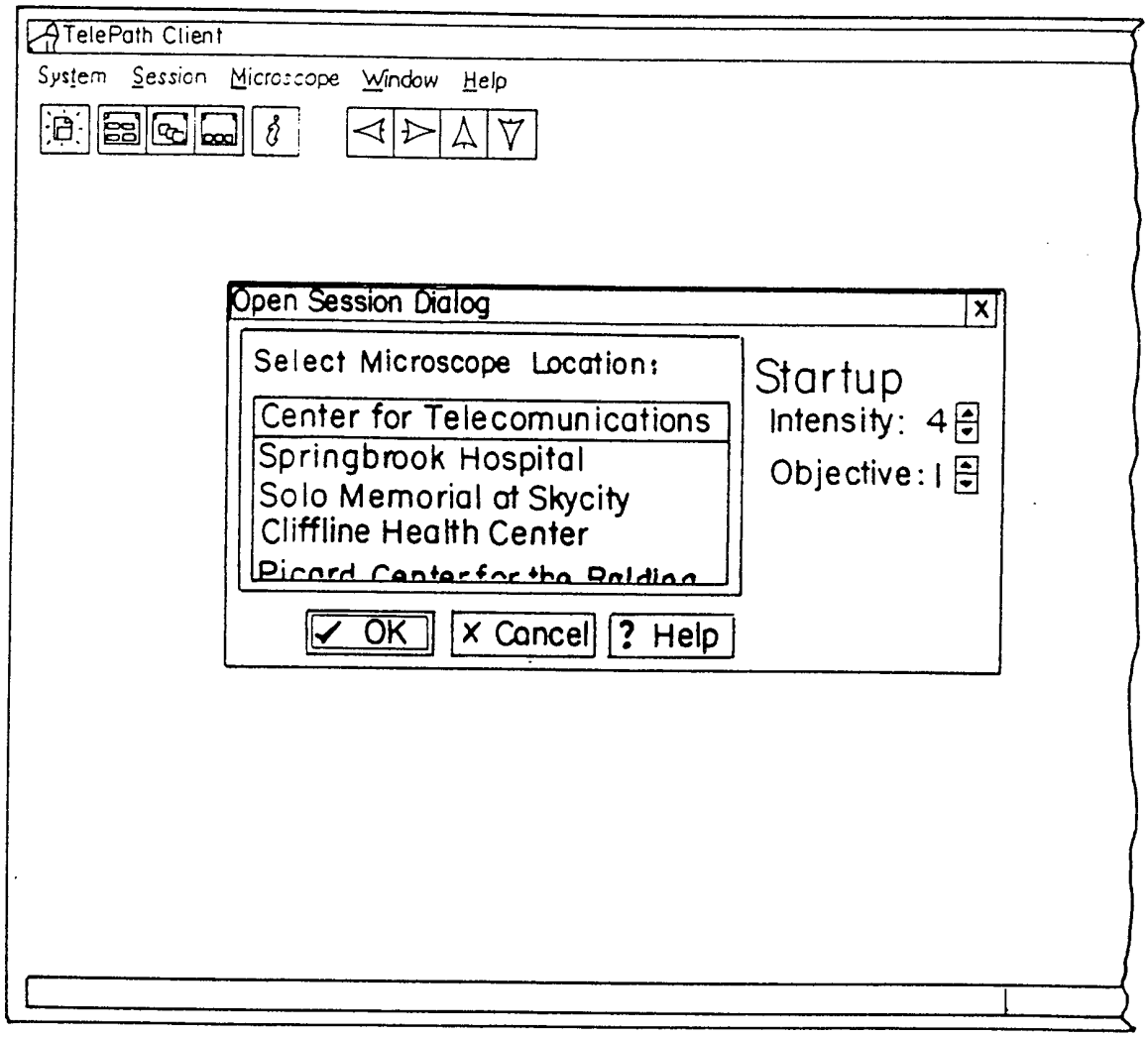

TelePath Client
System Session Microscope Window Help
Open Session Dialog
Select Microscope Location:
Center for Telecomunications
Springbrook Hospital
Solo Memorial at Skycity
Cliffline Health Center
Startup
Intensity: 4
Objective: 1
OK
Cancel
Help

Fig. 4

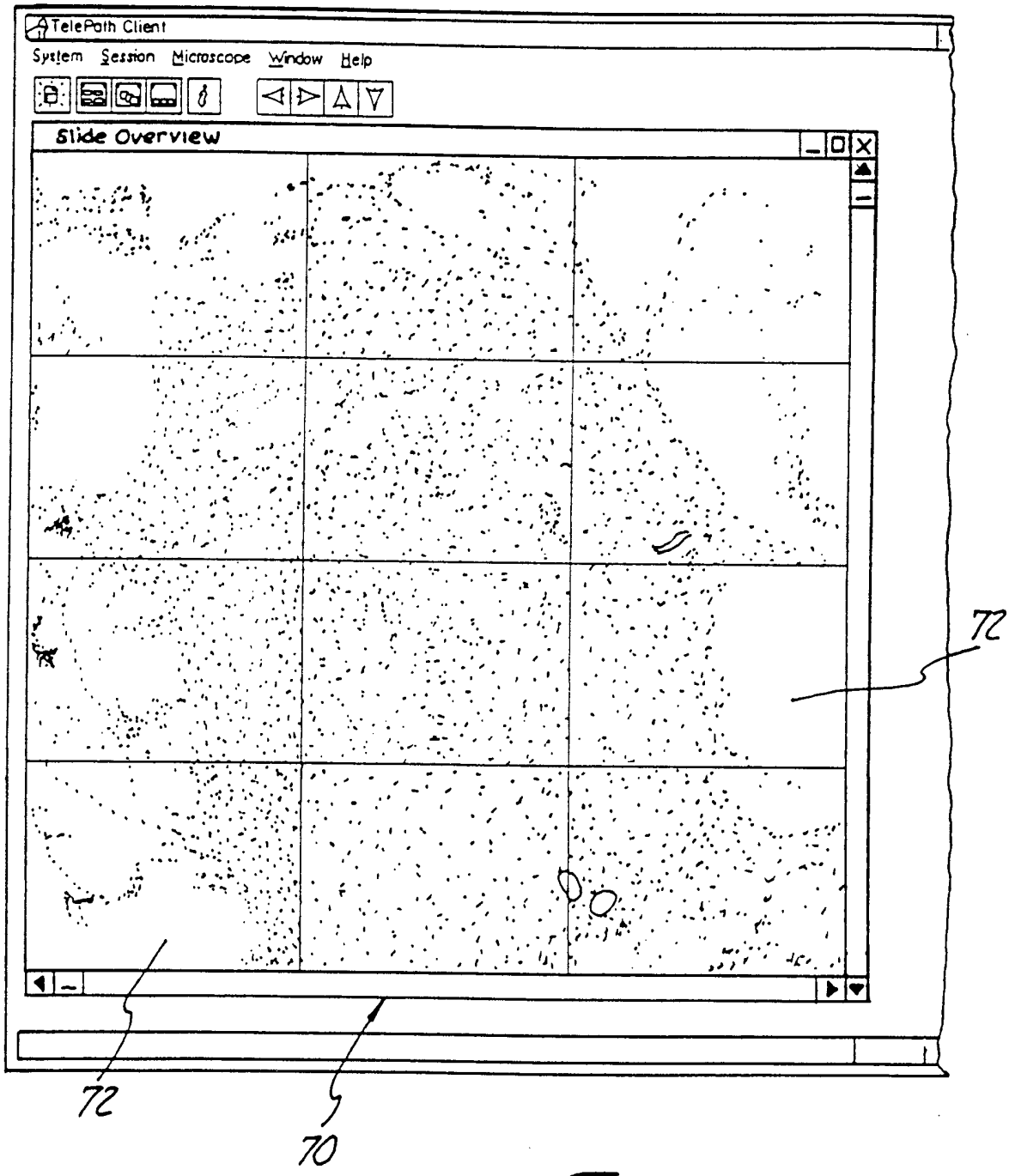

TelePath Client
System Session Microscope Window Help
Slide Overview
72
72
70

Fig. 5

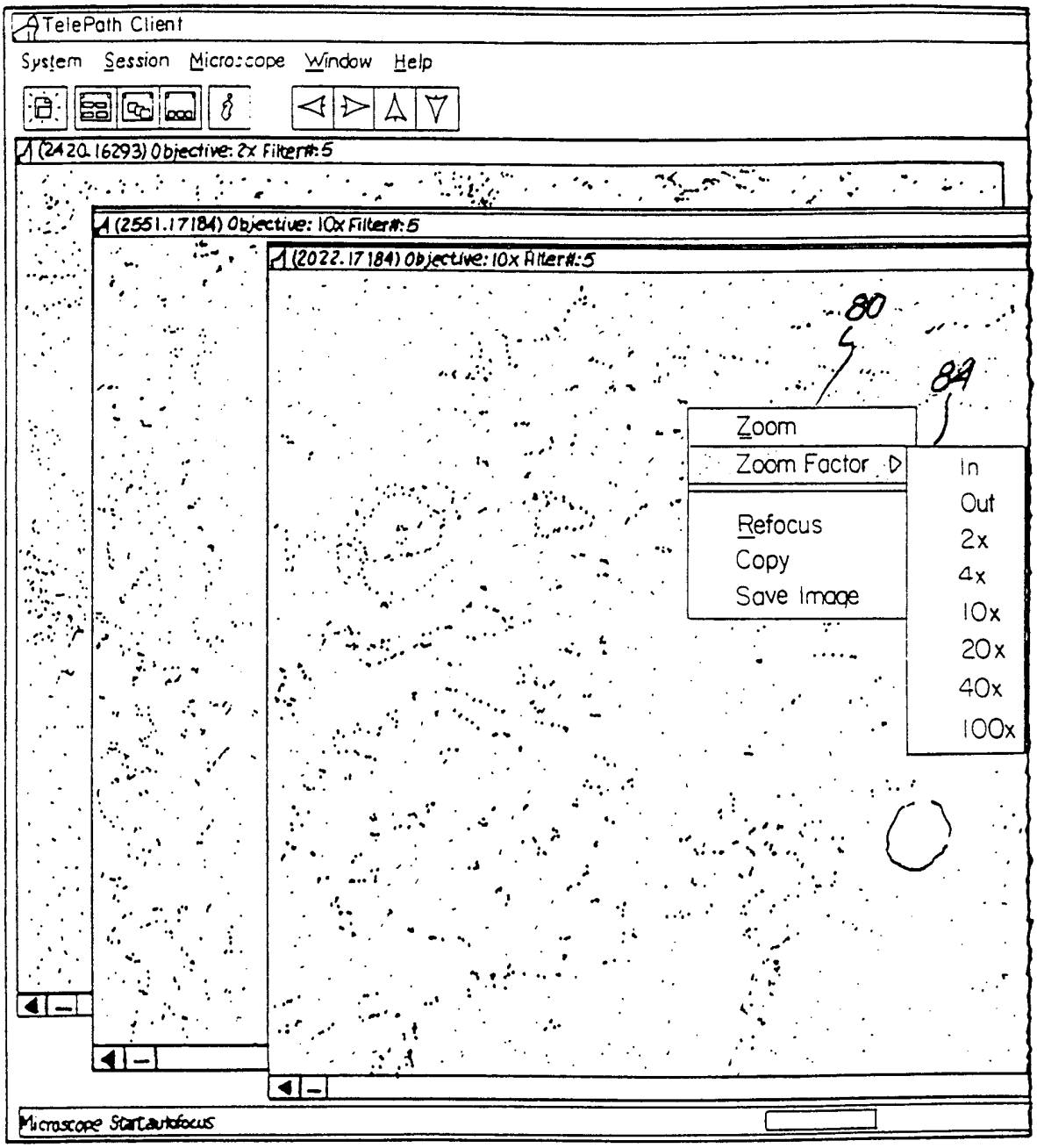

TelePath Client
System Session Microscope Window Help
(2420,16293) Objective: 2x Filter#:5
(2551,17184) Objective: 10x Filter#:5
(2022,17184) Objective: 10x Filter#:5
80
84
Zoom
Zoom Factor
Refocus
Copy
Save Image
In
Out
2x
4x
10x
20x
40x
100x
Microscope StartAutofocus

Fig.6

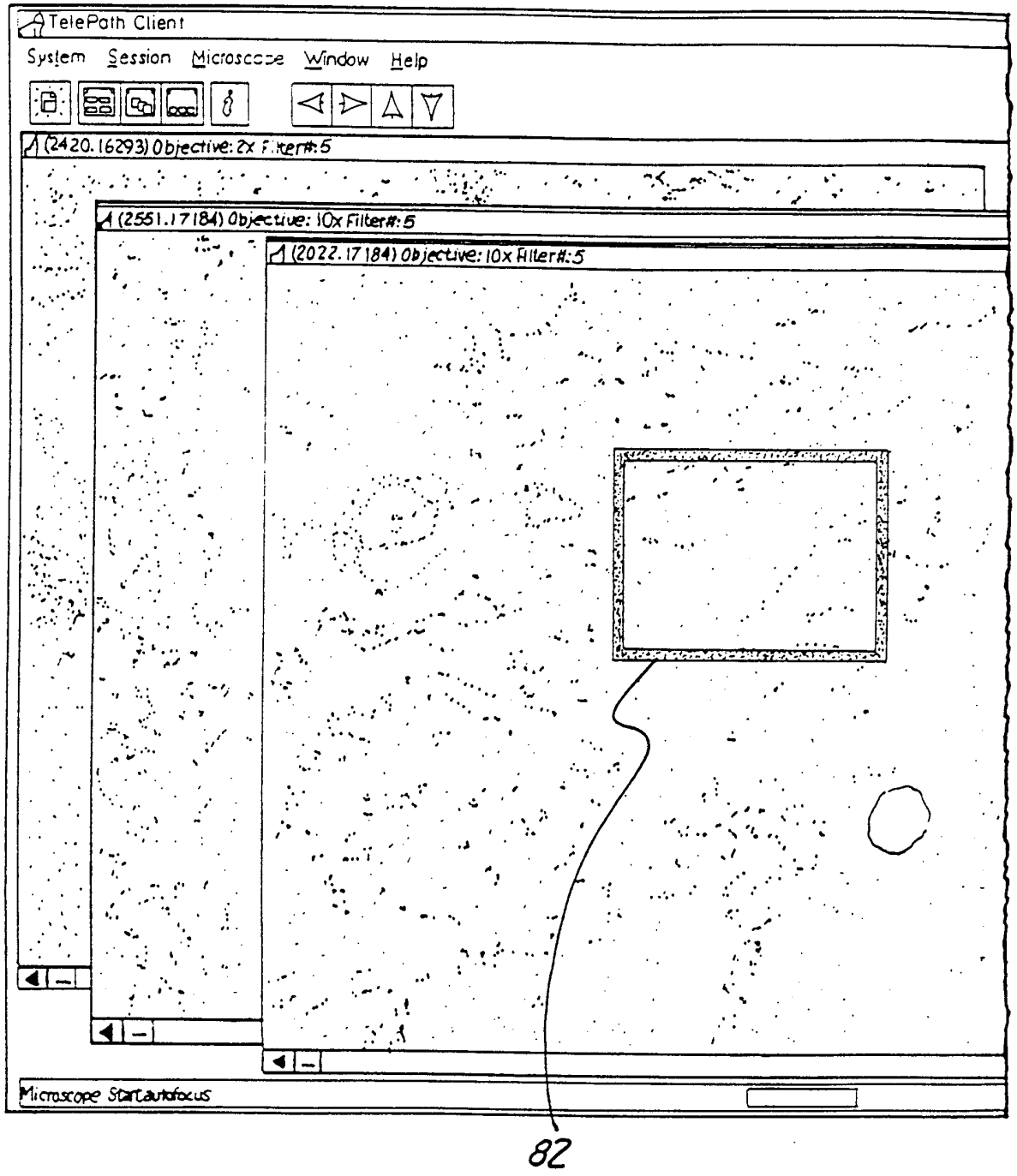

TelePath Client
System Session Microscope Window Help
(2420.16293) Objective: 2x Filter#:5
(2551.17184) Objective: 10x Filter#:5
(2022.17184) Objective: 10x Filter#:5
Microscope StartAutofocus
82

Fig. 7

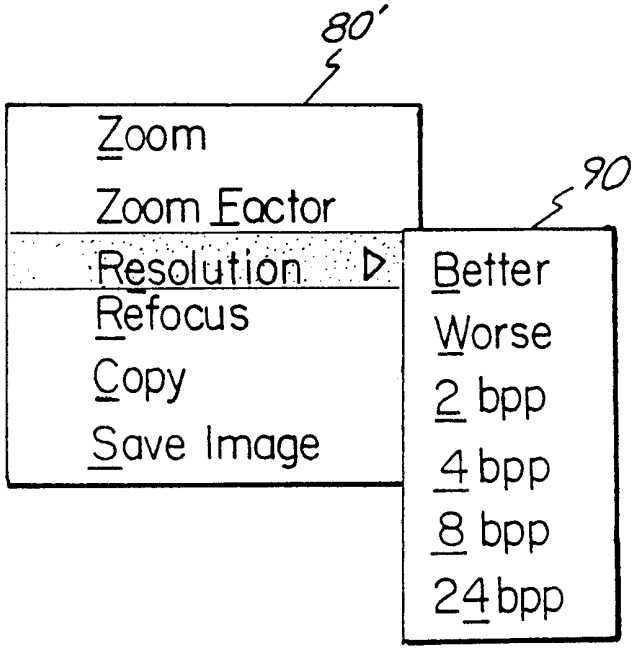

80'
Zoom
Zoom Factor
Resolution
Refocus
Copy
Save Image
90
Better
Worse
2 bpp
4 bpp
8 bpp
24 bpp

Fig. 8