

Subtitled Public

by Rafael Lozano-Hemmer

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GENERAL INFORMATION

Description

SUBTITLED PUBLIC consists of an empty exhibition space where visitors are tracked with a computerized infrared surveillance system. As people enter the installation, texts are projected onto their bodies: these “subtitles” consist of thousands of verbs conjugated in the third person and they follow each individual everywhere they go. The verbs appear at chest height, so it is not easy to read one’s own subtitle. Typically people look at other people to read the words; this produces an exchange of glances between visitors that is both playful and uncomfortable.

The exhibition room does not have any place where subtitles are not projected. Everyone who is in the room gets a word and thus is both observer and observed. The only way to get rid of a subtitle is to touch someone else: this transfers the word to the other person.

Every few minutes the piece is briefly interrupted as the raw video feeds from the tracking cameras are shown on the floor of the exhibition space. This is meant as a Brechtian “noticing of the knots”, a moment where the mechanisms of surveillance are revealed.

The piece invades the supposed neutrality of the space that museums and galleries set-up for contemplation, underlining the violent and asymmetric character of observation. Subtitled Public also highlights the danger of surveillance systems that typecast and try to detect different ethnic groups or suspicious individuals, as in the latest computer-vision devices that are being deployed in public spaces around the world. Finally, the installation is an ironic commentary on our era of technological personalization, literally branding all spectators and converting them into “thematic individuals”.



Sala de Arte Público Siqueiros in Mexico City, 2005.



The surveillance mechanism revealed.



Words are transferred between people who touch each other.

Production

Subtitled Public was originally developed in 2004 with the support of the Bancomer-BBVA foundation in Mexico City. The project was premiered at the “Dataspace” exhibition of Mexican Electronic Art, Conde Duque Center, Madrid, February 2005, during the ARCO Art Fair. It was later installed at the Sala de Arte Público Siqueiros (SAPS) in Mexico City, April-May 2005.

Currently the project exists in English and Spanish languages. Other languages can easily be added by giving the software a list of all the verbs of that language conjugated in the third person.

Catalogue information

“Subtitled Public” 2005. Variable number of surveillance pods, each consisting of one data projector, one nightvision camera, one PC and an infrared illuminator. Dimensions: variable.

Collections

The piece is sold as a unique work, with one artist proof. The purchase includes the technology to cover 100 square metres of exhibition space, corresponding to four surveillance pods. Additional surveillance pods can be added to cover any sized area, by purchasing or hiring additional PCs, projectors and cameras. Each pod will add 25 square metres of coverage and will cost around \$8,000 to buy.



Credits

Concept, direction: Rafael Lozano-Hemmer.

Programmers: Conroy Badger.

Production assistance: Jennifer Laughlin, Will Bauer, Ana Parga, Maria Parga, Natalie Bouchard, Susie Ramsay, Matthew Biederman, Tara DeSimone and Matthew Marino.

Selected reviews

- Barrios, José Luis, “Interview with Lozano-Hemmer”, Catalog Galerie Guy Bärtschi, Geneva 2005
- Benitez Dávila, Mónica, “Un Oráculo Electrónico”, Revista M, Mexico 2005
- Bosco, Roberta “El Ciclón Rafael”, Babelia, El País, Madrid 5/2/05
- Leñero, Isabel, “Luciano Matus y Rafael Lozano-Hemmer”, Proceso No. 1485, México, 2005
- Mac Masters, Merry, “Propuesta para rescatar espacios privados mediante la perversion de la tecnología”, La Jornada, Mexico 7/5/2005
- Medina, Cuauhtémoc, “Descripciones”, Reforma, Mexico 25/5/05
- Paz Gallardo, Deborah, “Lo sublime tecnológico o como entender el mundo de hoy”, Arteamérica 9, Cuba 2005
- Serra, Catalina “El Arte Mexicano Exhibe su Madurez”, El País, Madrid 11/2/05
- Springer, José Manuel “Mosaico y replejo, propuestas del arte mexicano en Madrid”, Replica 21, Mexico 29/3/05
- Springer, José Manuel “Público Subtitulado”, Replica 21, Mexico 20/4/05

Equipment

The piece functions with as many “surveillance pods” as necessary, but 4 pods are included with the purchase, covering up to 100 square meter area. Each surveillance pod consists of:

- Compact computer – a Shuttle PC running Windows 2000 or XP, or an Intel Mac mini running Windows XP SP2 under Boot Camp. The computer should have one 3 Ghz Pentium processor or a 1.66GHz Core Duo processor, 1GB RAM, 10GB disk, and 6-pin firewire connection. For example dimensions, weight and other specs, please visit:
http://sys.us.shuttle.com/G5_8300.aspx
<http://www.apple.com/macmini/>

- Compact projector – Minimum: a 2500 lumen projector with wide-angle optics and XGA native resolution (e.g. a Canon LV-7225). Ideal: a future projector that has as much native resolution as possible; the more resolution the less “pixelation” will be seen in the projected letters. The intensity is not as important: so long as the throw distances remain one projector for 25 square metres then 2500-3500 lumens will suffice.

- Surveillance camera – a night vision digital or analog camera with 0.1 lux sensitivity, fitted with wide angle lens and IR pass filter. The camera should capture at least 640x480 pixels 30 times per second in black and white. A suitable digital camera is the Unibrain fire-I board camera http://www.unibrain.com/Products/VisionImg/Fire_i_BC.htm if this is used then the camera should be connected with normal firewire cable to the PC, using firewire repeaters if necessary. Most analog cameras can also be used with an Imaging Source DFG/1394-1e video to firewire converter.

In addition to the pods, the installation requires the placement of an even array of inexpensive quartz halogen lights pointed straight down. These lights are covered with Congo Blue filter (Roscolux 382, GAM 930 or Lee 181) and a diffuser such as Roscolux 116. This allows the room to produce an even dark blue illumination that is rich in infrared wavelengths.

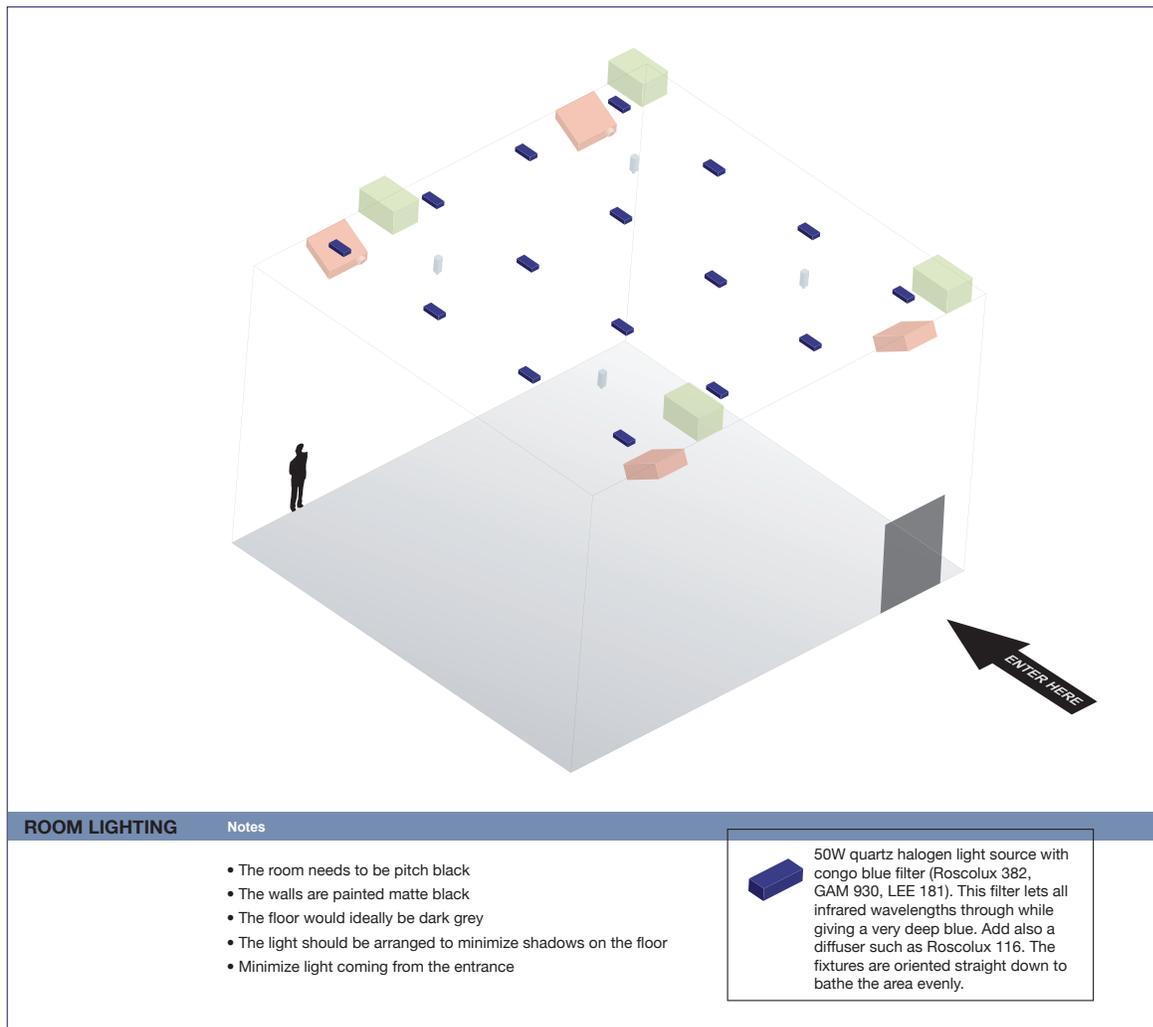
The entire installation may be controlled by a single PC or Mac, same model as above, which is connected to the others by Ethernet or WIFI as a local network. This PC or Mac can run VNC so that the other computers can be controlled remotely.



SET-UP AND CALIBRATION

Exhibition room

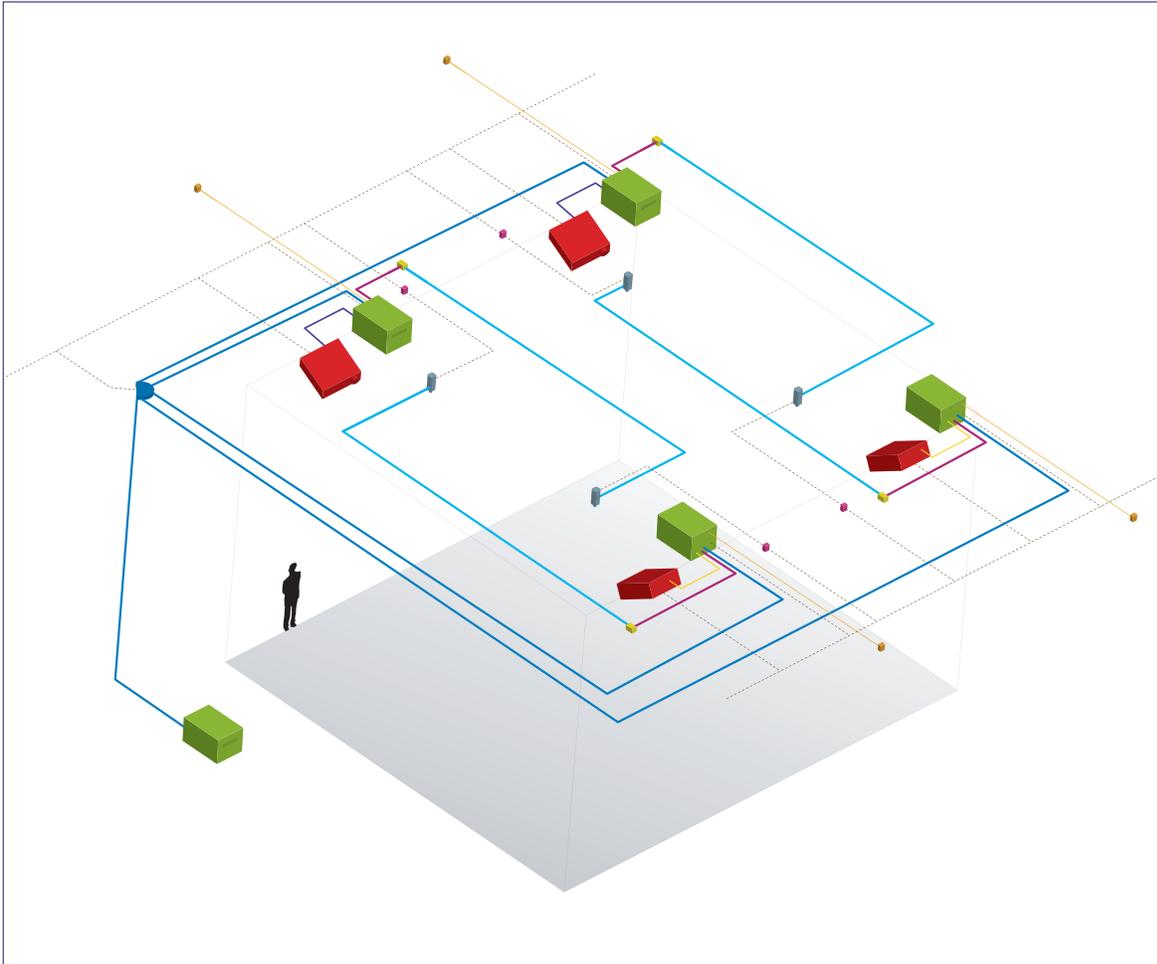
The cameras and projectors are set up in pairs on opposing sides of the exhibition room. Each pair should be hung from the ceiling so that ideally there is a 45 degree angle to the floor.



Depending on the optics for the cameras and projectors different-sized rooms can be accommodated, but the minimum size is an open room measuring 9 x 9 m and a height of at least 4 m. The room should be darkened completely and particular attention should be given to not having light enter from the entrance(s). This is necessary because the surveillance system works with background subtraction and thus depends on a constant illumination, i.e. if there is natural light the system might try to subtitle shadows produced by clouds that might temporarily block the sun. There can be as many entrances and exits as desired.

Each pod will cover around 25 square metres of area so the following diagrams show four pods covering a 100 square metre room. You may add additional pods but please note that it is very important conceptually that there be no place in the room where you do not get tracked, i.e. everybody who is inside the installation should get a subtitle, there should be no “safe spot” where you can just be an observer.

Connections

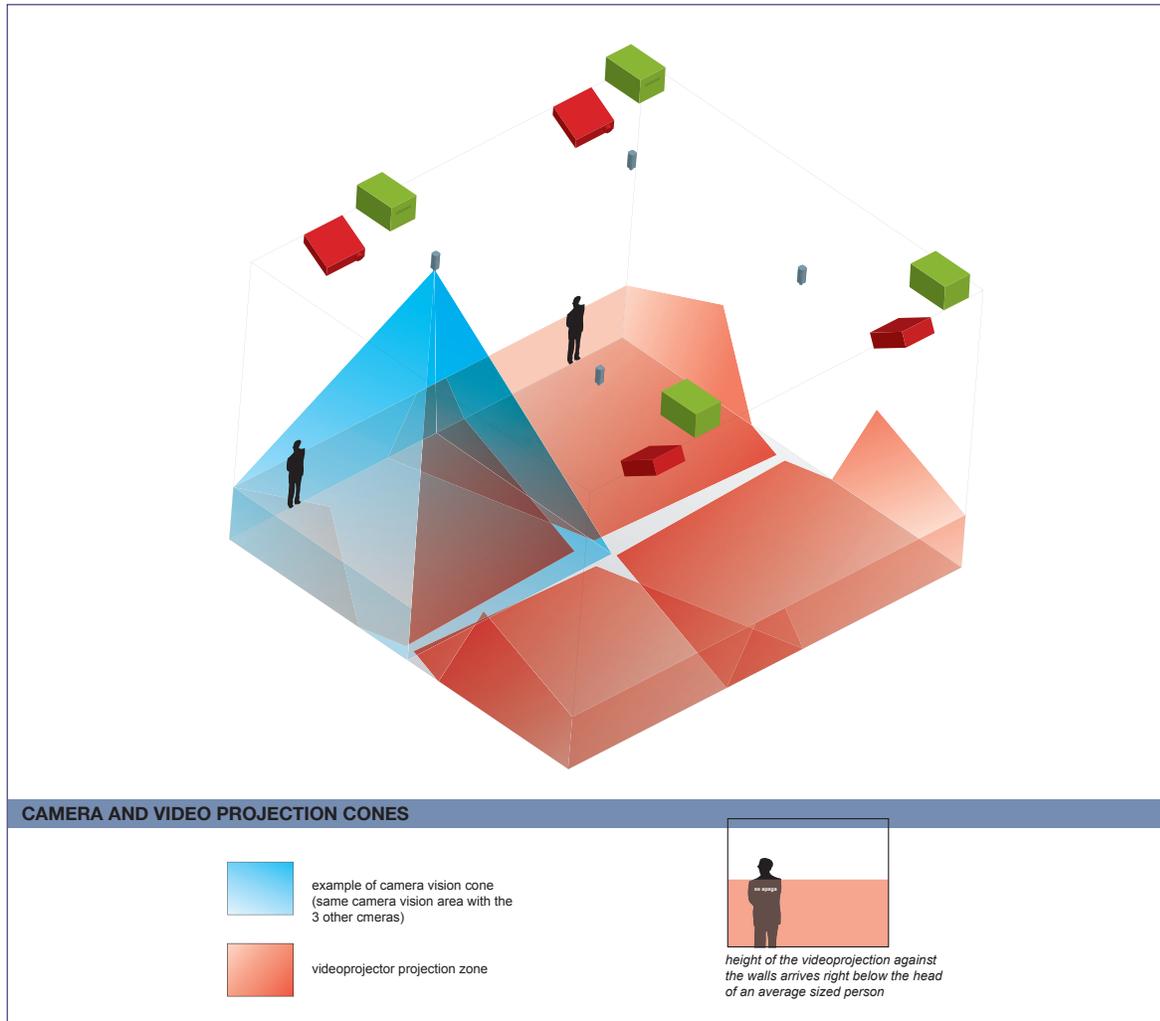


HARDWARE AND CABLES		Hardware	Amount	Length	Details
	External switch to restart the computer		4	any	A simple contact closure
	Ethernet hub		1		100Mbit is fine
	Computer PC shuttle or Mac mini		5		Min 1.5GHz, 1GB RAM
	Analog camera with wide optics and IR filter		4		Min 0.01 Lux sensitivity
	Videoprojector (~ 45 degree angle)		4		Min XGA, 3000 lumen
	Analog to digital video converter		4		Imaging source DFG/1394-1e
	Camera power supply		4		
	Ethernet cable		5	up to > 100 m	A closed wifi network is possible
	Firewire cable		4	< 10 m	Can use repeaters to extend
	VGA or DVI cable		4	depends	Can use repeaters to extend
	Analog video cable		4	< 100 m	
	Electrical power (various cables to outlets)		14	any	Can use 110 to 220 V

Once the computers, projectors, quartz lamps and cameras are hung as in the diagram, please make the following connections:

1. Each camera to its corresponding PC using a firewire connection.
2. Interconnect the PCs in a local network WIFI or Ethernet running VNC.
3. Connect each projector to its corresponding PC using a VGA or preferably a DVI connection.
4. Give 110 or 220V power to all the elements.

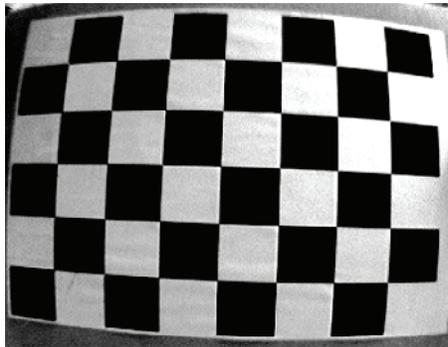
The projectors should be set to their widest angle and then lowered until they each cover their respective area. No keystoneing should be used as our software adds its own keystone correction.



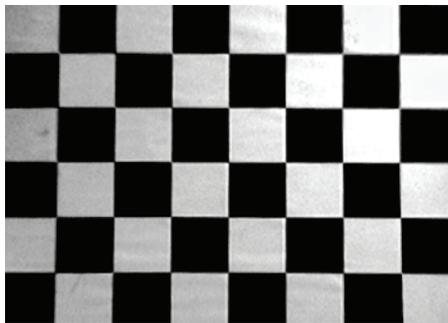
Lens calibration

The goal of the lens calibration is to remove the effects of radial distortion that occurs in any traditional lens assembly. The math for the program is based on the “pinhole” lens model. This model assumes a perspective mapping between the world and the camera CCD surface. Straight lines in the real world must map to straight lines in the camera image. This calibration only needs to be done once for each lens it is not necessary to do it everytime the piece is set up.

Please note: if you have already sent us CAD floor plans and elevations of the exhibition room we can choose the appropriate lenses and pre-calibrate them for you; if so, you can skip ahead to section “System calibration sequence” .

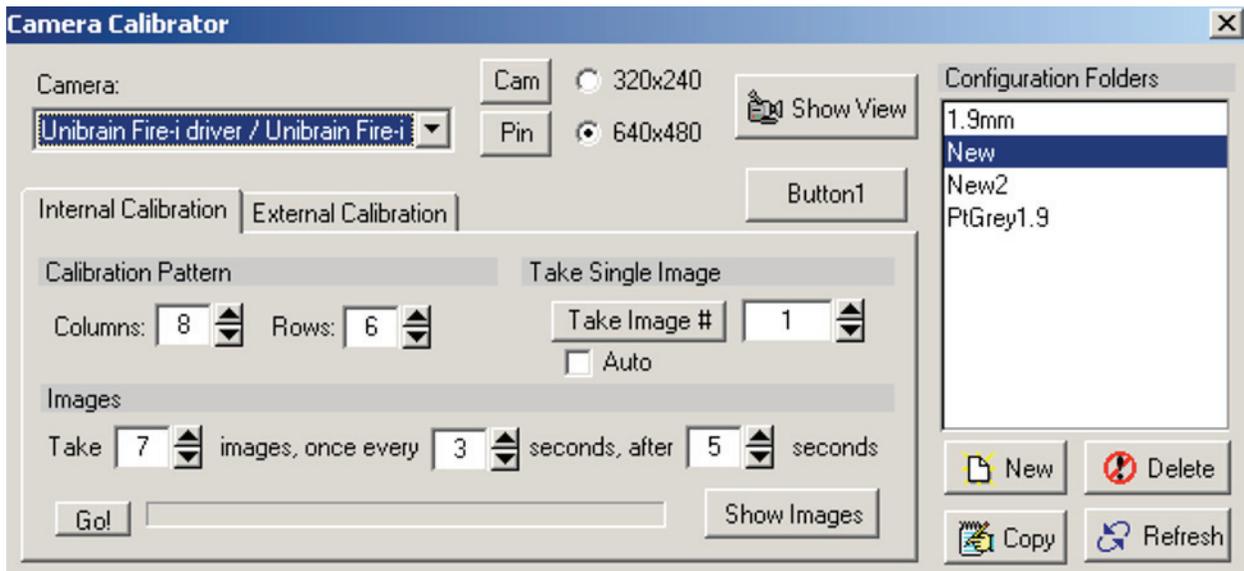


Here’s an example (see picture left) of radial distortion. Notice the lines in the chessboard image as well as the edges of the paper are curved. In real life, these lines are really straight.



Below is the same image after the effects of radial distortion are removed. Notice the lines are now straight, just like in the real world. Also notice the edges of the image are gone. The image has been effectively stretched from the edges, and the extreme edges are lost. This means that you need to pick a lens that appears to initially give you more coverage than you actually need. To remove the effects of radial distortion, there’s a program on the CD called “Calibrate”.

This program can do an internal (lens) calibration as well as an external (pose) calibration. Here’s a screenshot of Calibrate’s main screen:



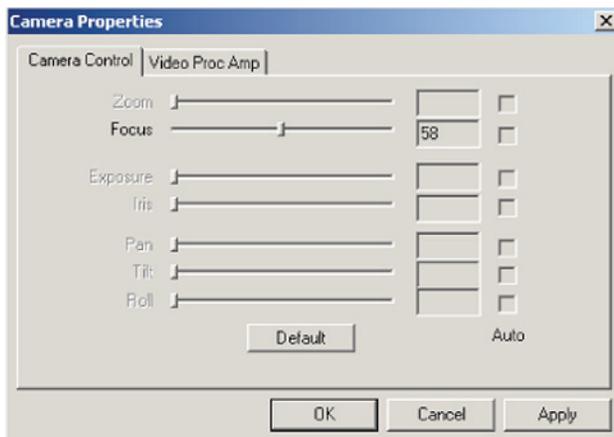
The list of configurations is on the right. You can create a new default configuration or create a copy of the current configuration. In addition, you can rename a configuration by typing directly in the configuration list on the right. Currently there’s no way to delete a configuration from the software. You can

easily do so from windows by selecting the configuration folder from an explorer window and pressing delete. Note that the program remembers the last configuration loaded, and if it notices the folder missing it will recreate it for you and add a default configuration. Switch to another configuration before deleting any old configurations, or the old one will be recreated by the program when it launches again.

You'll want to start with a new configuration, so click "New". Select your camera from the drop-down menu on the left. Select the "640x480" resolution since this is what "Subtitled Public" uses. If you press the "Show View" button, you'll be able to see the current camera view.

To perform the calibration, you'll need to have a calibration pattern mounted on a firm flat backing, such as a clipboard. You can print the pattern out right from the program. We have always used the 8x6 pattern.

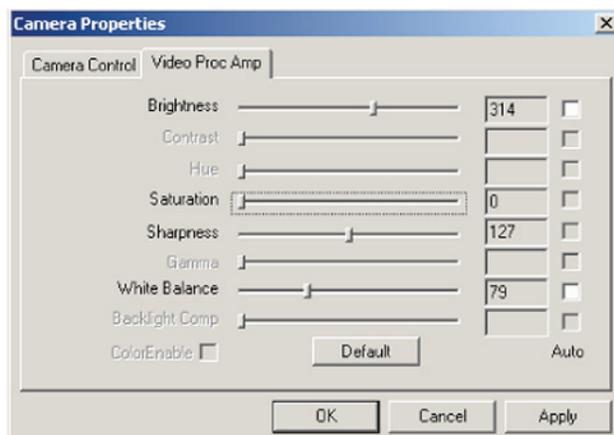
Once you have your pattern printed out and mounted, press the "Show View" button to see the camera view. Adjust the camera settings so you get a clean, well exposed, image. Press the "Cam" button to bring up the adjustment screen.



This is the adjustment screen for an ADS pyro web camera under XP. Both tabs are shown. Other cameras may have more or less controls or tabs.

Here are some tips on adjusting the image.

- Since the exhibition room will have steady, controlled, artificial illumination, then all camera settings should be set to manual (e.g. exposure, brightness, white balance check boxes should not be checked).



- Go for maximum exposure without clipping and maximum contrast. If the image is too washed out, turn down the brightness. Only then if the image is still too bright, bring down

the contrast. Try to leave the exposure at maximum if you have control over it.

- Subtitled Public does not use colour. If you are using a colour camera, turn the saturation all the way down. Although the image is automatically converted to grey scale after the radial distortion, you should take the colour out now.

That way, the image that you see, and are adjusting to is the same image (minus the radial distortion) that the tracking algorithm will see.

- The sharpness setting is critical for the internal calibration. If the lines are too sharp, there will be artefacts that will throw off the calibration routines. If the lines are too blurry, the computer won't be able to find the corners of the chessboard image.



For example, the image on the left is a bit blurry, the one in the middle is just right and the one on the right has artefacts from over-sharpening.

Once you have your camera adjusted close the adjustment screen.

Taking calibration images

You can choose the number of images you want to use for the calibration. You'll need at least 3. Using more images will give you a better calibration. We recommend the default 7 images.

You can take the pictures one at a time or in sequence. Pressing the "Go" button near the bottom will start the computer taking pictures automatically in sequence, with a beep after each picture is taken.

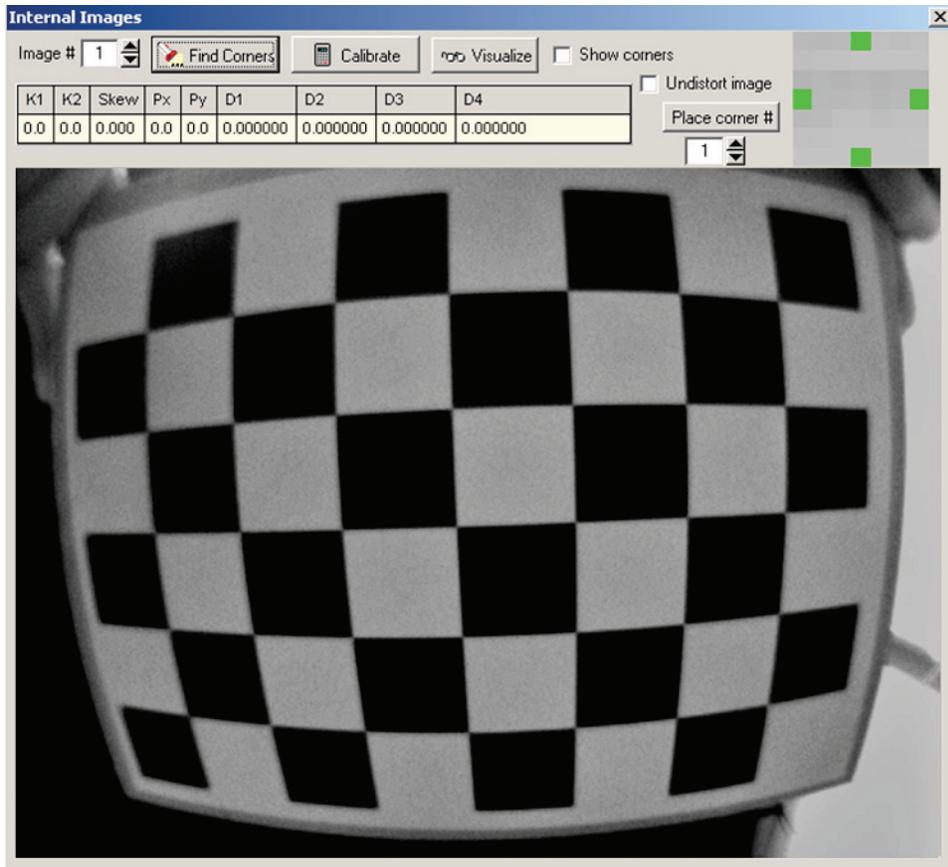
You can also take a single picture by selecting the image # to take and pressing the "Take image #" button. This is handy if the computer failed to find the chess board corners in some of the images but not all. It's also nice because it gives you instant feedback on whether the image was good or not. If the image passed, the program's title bar will say "Ok". If another image needs to be taken, it will say "Bad".

Start with the automatic method, and replace the failed images one at a time with the single shot option. After you've taken your images, press the "Show Images" button, taking you to the internal calibration screen, shown right.

You can select the image to view from the image # edit. Press "Find corners" to have the computer find the corners for you. This will usually result in about half the images failing and half passing.

If 4 of the images pass, for example, and 3 fail, simply go back to the previous screen and take single shots of the failed images. Select the image # in the edit and press the "Take image #" button until the caption says ok.

Once you have a set of images that the PC is happy with, you can verify the corners by checking off the "View corners" check box. The corners should be numbered sequentially and placed at the intersections of the chessboard squares.



To perform the actual internal calibration, press the “Calibrate” button. The table will fill with values regarding the lens’ distortion. To test the calibration, check the “Undistort image” check box. Check all the images with the “Image #” edit to make sure all the lines in the images appear reasonably straight.

You can now check the camera view to see what kind of coverage you’re going to have after the lens distortion correction. Go back to the main screen.

By selecting live feed and undistort from this screen you will see the live feed of the camera corrected for radial distortion. Hopefully your camera can still see enough of the tracking area. If not, you can only go back and pick a wider-angle lens.

Exit this program and you’re ready for the next step. Please note that this lens calibration is only needed once per lens and camera, if you move the installation to a different exhibition room you will not need to redo this calibration if you are using the same lens and camera.

System calibration sequence

Start the PCs and automatically the “Subtitled Public” software will run. Right click on the screen so that you can enter the set-up screen. Press the calibration button and follow the on-screen instructions so that the system can know with precision where the camera is in relation to the projector. The calibration procedure involves matching points shown by the projectors to points seen by the cameras. You must also enter the relative position of each pod as indicated by the installation wizard. In the screen you can also enter the desired language of the installation. Currently you can choose between English, Spanish or both.

Start and shutdown procedures

To turn the installation ON:

1. Power ON the projectors
2. Power ON the quartz lights
3. Power ON the PCs, -- the software will start-up automatically.

To turn the installation OFF:

1. Shutdown the computers using either the VNC control computer, external remote switches or the PCs internal shutdown timer.
2. Turn OFF the projectors
3. Turn OFF the quartz lights

PRESERVATION NOTES

The piece runs using software developed by engineer Conroy Badger from APR Inc. in Edmonton, Canada. He can be contacted at Tel 780-450-8261 or at conroy.badger@shaw.ca. The software is custom-programmed in Delphi using Open computer vision libraries from Intel and it runs on Windows 2000 or XP. The source code is available to the collector so that in the future the project can be recompiled for a different operating system.

The software will automatically use any and all available resolution available from the connected projector and graphics card. Currently the project is running with XGA resolution 1024x768 pixels but in the future projectors with much more resolution could be used to minimize the pixelated quality of the text when participants are far away. For example, currently we spread 1024 pixels over 6 m, so in fact we can only have 170 pixels to write a word when the person is very far away from the projector. This “worst case scenario” is acceptable but clearly more resolution would be better. An HD projector could do 1920 pixels over 6 m = 320 pixels per meter, which would make the word easier to read and more defined. When these future projectors are used, it will be possible to also extend their range so that instead of only covering 25 square metres they can cover much more area provided their brightness is also increased (by the square of the distance added). Please note however that the priority is to add resolution not range, it is preferable to add more projectors for more range and use the resolution for better text rendering.



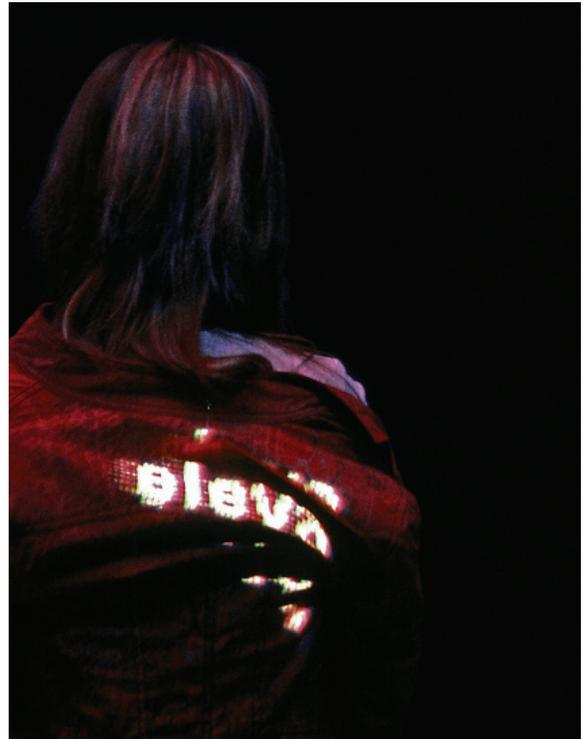
It is possible to use other sources of infrared light other than the quartz lamps with filters. For example IR LED panels could be used or other future technology. These should have diffusers and be distributed all over the exhibition room to avoid shadows as much as possible. If other IR sources are used then the curator will need to decide if s/he wants to add additional lighting, such as fluorescent tubes so that the room is not in complete darkness. i.e. the artist approves for the room environment to have a different colour than congo blue. If possible please consult with the artist before making this decision.

When in the future a superior computer vision tracking technology is developed this can be used for the piece. In particular it would be great to be able to better discriminate when a detected presence is made of one big person or a couple hugging. Also, improvements in latency, stability and precision would be welcome.



From the artist's perspective, the project as it is now is beautiful and delivers the required effect. However, the artwork is not the tracking system and algorithms currently used but the concept of subtitling the public. In this sense he is open to future ways to accomplish the effect.

In the future it is possible to add more languages to the project, for example for when the project tours different countries. To do this all you need to do is prepare verb lists in the desired languages and replace the ones that come with the project. The verb lists should be saved as txt files, with one entry per line, with no spaces, and with every verb of the language conjugated in the third person.



APPENDIX I
Fire-i Board Digital Camera

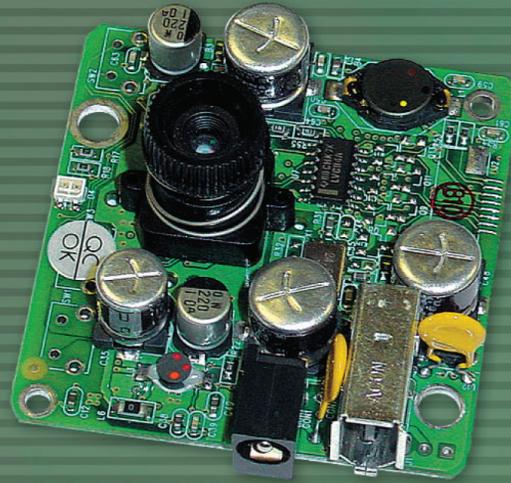
Fire-i™ BOARD DIGITAL CAMERA

1394 400Mbps imaging inside your product!

Fire-i™ Board Color Digital Camera is a one-board fully operational 1394 400Mbps camera, complying with IIDC 1.04 specification for industrial uncompressed VGA picture acquisition. The latest 1394 TI chipsets and Sony's Wfine CCD sensor give a high quality subassembly for OEM use.

Fire-i™ Board offers:

- 400 Mbps 1394a compliant
- IIDC v1.04 Industrial Camera spec. compliant
- Uncompressed VGA color picture up to 30 fps
- Removable second 1394 connector
- Additional power jack input 8-30 VDC
- Removable built-in lens
- Full frame electronic shutter with progressive scanning
- Square pixels, RGB Bayer 1/4" CCD
- Built-in color bar generator
- Bundled with Fire-i™ "ready to use" software & Microsoft compatible drivers



1394 400Mbps imaging inside your product

CCD FEATURES:

- Progressive scanning allows full frame uninterlaced acquisition and shuttering
- High identical horizontal and vertical resolutions, 400 TV-lines
- 1/4" CCD, 659(H)x494(V) square pixels
5.6 μm (H) x 5.6 μm (V)
- RGB primary color filters on chip, Bayer array
- VGA output up to 30 frames per second
- Low smear, high sensitivity, low dark current
- Excellent anti-blooming
- Continuous variable electronic shutter

CAMERA BOARD FEATURES:

- 640x480 VGA out in YUV4:1:1, YUV4:2:2, RGB-24 and Y-8
- up to 30 fps depending of output mode
- built-in reference color bars & linear ramps generator
- 2nd 1394 port, removable
- 8 to 30 VDC power supply, by any 1394 input or by separate jack
- outstanding low power consumption 1.0 W max, 0.9 W typical
- software controllable sleep mode, 0.4 W

unibrain®
The 1394 Innovators



www.unibrain.com

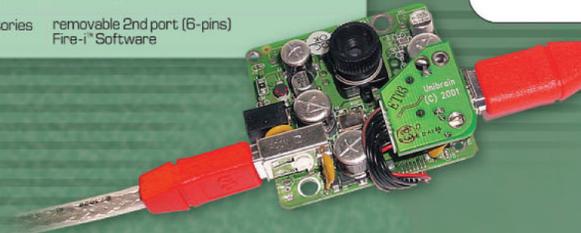
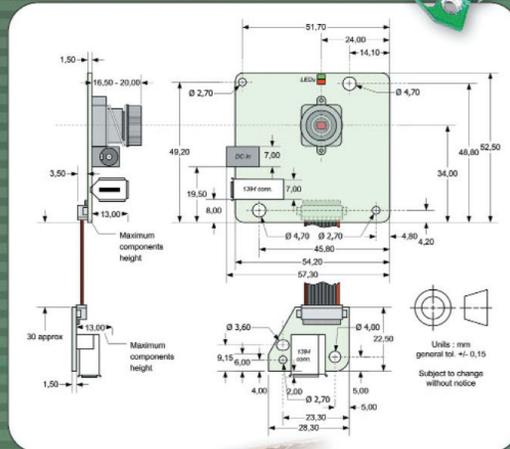
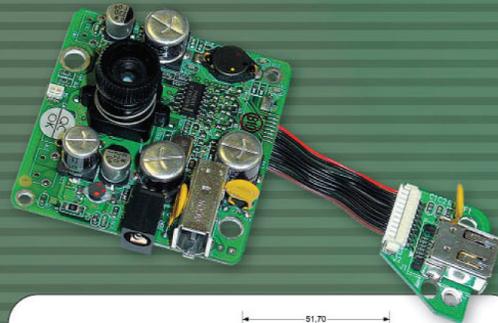
Fire-i™ BOARD DIGITAL CAMERA

1394 400Mbps imaging inside your product!



Fire-i™ Board SPECIFICATIONS

Interface	IEEE-1394a (FireWire) 400 Mbps, 2 ports (6-pins)
Camera Type	IDC-1394 Digital Camera, V1.04 Specification compliant
Sensor Type	Sony W/fine 1/4" CCD Color, progressive, square pixels
Resolution	VGA 640 x 480
Optics	built-in f 4.65 mm lens, removable, anti-reflective coating
Video Modes	YUV (4:1:1, 4:2:2, 4:4:4), RGB-24bit, Monochrome-8bit
Frame Rates	30, 15, 7.5 and 3.75 frames per second
Gain	Automatic or Manual Control 0-30 dB
Shutter	Automatic or Manual Control 1/3400s-1/31s
Gamma	ON/OFF (visual use/image processing use)
White Balance	Automatic or Manual Control
Color Saturation	Adjustable
Backlight Compensation	6 modes + OFF
Sharpness	Adjustable
Special Features	Software sleep mode, Color bar generator
Power Supply	8 to 30 VDC, by 1394 bus or external jack input Consumption 1W max, 0.9 W typical, 0.4 W sleep mode
Dimensions (WxHxD)	57.3 x 52.50 x 25 mm
Housing & Weight	No housing, 35 gr
Included accessories	removable 2nd port (6-pins) Fire-i™ Software



Bulk packaging contains:

- 50 Fire-i™ Board Digital Cameras
- One CD with Fire-i™ Software, drivers and documentation

Boards Supported

Operates with any third party IEEE-1394 PCI or PCM/CIA OHCI compliant adapter, or any Desktop/Portable PC with built-in IEEE-1394 support.

OS Supported

Windows 98SE/Me/2000/XP/Mac OS 9.x/10.x

Do not hesitate to contact us about your project!

unibrain
The 1394 Innovators

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e-mail: sales@unibrain.com

APPENDIX II
Information on Apple Mac Mini

Technical Specifications

In the Box

- Mac mini
- Apple Remote
- Power cord
- Install/restore DVDs
- Printed and electronic documentation

Processor and memory

- 1.5GHz Intel Core Solo or 1.66GHz Intel Core Duo processor
- 2MB on-chip L2 cache
- 667MHz frontside bus
- 512MB of 667MHz DDR2 SDRAM (PC2-5300) on two DIMMs; supports up to 2GB



Size and weight

- Height: 2 inches (5.08 cm)
- Width: 6.5 inches (16.51 cm)
- Depth: 6.5 inches (16.51 cm)
- Weight: 2.9 pounds (1.31 kg)

Peripheral connections

- One FireWire 400 port (8 watts)
- Four USB 2.0 ports (up to 480 Mbps)



Graphics and Video Support

- Intel GMA950 graphics processor with 64MB of DDR2 SDRAM shared with main memory¹
- DVI video output to support digital resolutions up to 1920 by 1200 pixels; supports 20-inch Apple Cinema Display and 23-inch Apple Cinema HD Display; supports coherent digital displays up to 154MHz; supports noncoherent digital displays up to 135MHz
- VGA video output (using included adapter) to support analog resolutions up to 1920 by 1080 pixels
- S-video and composite video output to connect directly to a TV or projector (using Apple DVI to Video Adapter, sold separately)



Communications

- Built-in 10/100/1000BASE-T Gigabit Ethernet (RJ-45 connector)
- Built-in 54-Mbps AirPort Extreme wireless networking (based on 802.11g standard)
- Built-in Bluetooth 2.0 + Enhanced Data Rate (EDR) up to 3 Mbps
- Optional external Apple USB Modem



Audio

- Built-in speaker
- Combined optical digital audio input/audio line in (minijack)
- Combined optical digital audio output/headphone out (minijack)

Storage

- 60GB or 80GB 5400-rpm Serial ATA hard disk drive; optional 100GB or 120GB drive²
- One of the following optical drives:
 - Slot-loading Combo drive (DVD-ROM/CD-RW): reads DVDs at up to 8x speed, writes CD-R discs at up to 24x speed, writes CD-RW discs at up to 16x speed, reads CDs at up to 24x speed
 - Slot-loading SuperDrive with double-layer support (DVD+R DL/DVD±RW/CD-RW): writes DVD+R DL discs at up to 2.4x speed, writes DVD-R and DVD+R discs at up to 8x speed, writes DVD-RW and DVD+RW discs at up to 4x speed, reads DVDs at up to 8x speed, writes CD-R discs at up to 24x speed, reads CD-R discs at up to 16x speed, reads CDs at up to 24x speed



Software

- Mac OS X v10.4 Tiger (includes Spotlight, Dashboard, Mail, iChat AV, Safari, Address Book, QuickTime, iCal, DVD Player, Xcode Developer Tools)
- iLife '06 (includes iTunes, iPhoto, iMovie HD, iDVD, iWeb, GarageBand), Microsoft Office 2004 for Mac Test Drive, iWork (30-day trial), Quicken 2006 for Macintosh, Big Bang Board Games, Comic Life, Omni Outliner, and Apple Hardware Test
- Front Row



Electrical and environmental requirements

- Meets ENERGY STAR requirements
- Line voltage: 100–240V AC
- Frequency: 50Hz to 60Hz, single phase
- Maximum continuous power: 110W
- Operating temperature: 50° to 95° F (10° to 35° C)
- Storage temperature: -40° to 116° F (-40° to 47° C)
- Relative humidity: 5% to 95% noncondensing
- Maximum altitude: 10,000 feet

Configurations

	1.5GHz Mac mini (MA205LL/A)	1.66GHz Mac mini (MA206LL/A)
Processor	1.5GHz Intel Core Solo	1.66GHz Intel Core Duo
L2 Cache	2MB Shared	
System bus	667MHz	
Memory	512MB of 667MHz DDR2 SDRAM (PC2-5300), supports up to 2GB	
Hard drive	60GB 5400-rpm Serial ATA2	80GB 5400-rpm Serial ATA
Optical drive	Slot-loading Combo drive (DVD-ROM/CD-RW)	Slot-loading SuperDrive with double-layer support (DVD+R DL/DVD±RW/CD-RW)
Graphics	Intel GMA950 graphics processor with 64MB of DDR2 SDRAM shared with main memory ¹	
Ports	One FireWire 400 port (8 watts); Four USB 2.0 ports (up to 480 Mbps); DVI output; VGA output (using included adapter); S-video and composite video output ⁴	
Audio	Built-in speakers, combined optical digital audio input/audio line in, combined optical digital audio output/headphone out	
Networking	Built-in 10/100/1000BASE-T (Gigabit)	
Wireless	Built-in 54 Mbps AirPort Extreme Wi-Fi (802.11g) ³ ; built-in Bluetooth 2.0+EDR (Enhanced Data Rate) module.	