Thermo-Key:
Human Region Segmentation from Video Using Thermal Information

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Example Video (1)

Example Video (2)

Example Video (3)

Example Video (4)

Introduction (1)

- Image segmentation is a method of dividing an image into several regions.

Introduction (2)

- Human region segmentation is very important for a lot of applications.
  - Superimposing onto a synthetic image
    - Weather forecast
  - Image communication
    - face to face communication
    - protecting personal privacy
  - Recognizing facial expressions
  - Detecting an intruder

Introduction (3)

- The goal of this project is human region segmentation from video in real time.
- We don't want to set up a special environment.
- We don't want to restrict the person to be segmented in a particular position.

Introduction (4)

- These availability and interactivity will enhance the applicability of the human region segmentation.
  - Entertainment
  - Virtual reality and augmented reality
  - Outdoor applications
  - Presentation

Related Work (1)

- Chroma-Key (including Ultimatte)
  - A blue (or green) screen is utilized as a well-controlled background including sophisticated lighting condition. This is a strong restriction of this method.
  - As you know, it is widely used especially in broad casting.
  - It is well designed for human skin color (or blue eyes).

Related Work (2)

- Background Subtraction
  - The color values of pixels are compared between the current image and the previously-captured background image.
  - Such objects those have the same color as the background cannot be segmented.

Related Work (3)

- Depth-Key
  - The distance between a capturing system and objects are measured or estimated. This is not always perfect.
  - All the objects placed in particular distance region will be segmented. This could be either merits and demerits.

Related Works (4)

Comparison of related works

Method	Category	Restriction	Target
Chroma-Key (Ultimatte)	Active (lighting)	Blue screens	Mainly human
Background Subtraction	Passive	Different color	Any objects
Depth-Key	Active is better	Standing position	Any objects
Our Proposal			

Our Proposal (1)

- Assumption
  - The human body has higher temperature than the surroundings.
    - Warm objects will be segmented independent of colors and distance.
    - Warm environments and cold clothes would be bad for our assumption. For this problem, we could implement a kind of hybrid method that utilizes thermal and color information.

Our Proposal (2)

- Good News
  - By capturing infrared rays, we can measure the temperature distribution in a scene.
  - This is a passive method, and could be robust in comparison with the depth measurement used in the depth-keying.
  - Thermal vision camera is already commercially available from $10,000, and widely used for medical purposes. Ours is about $40,000.

Our Proposal (3)

- Thermo-Key
  - A thermal vision camera is used for capturing the temperature distribution.
  - Thermal data is the key for segmenting human region from a color image.
  - This method can be specialized for human region, since we know the approximate temperature of human body.

Our Proposal (4)

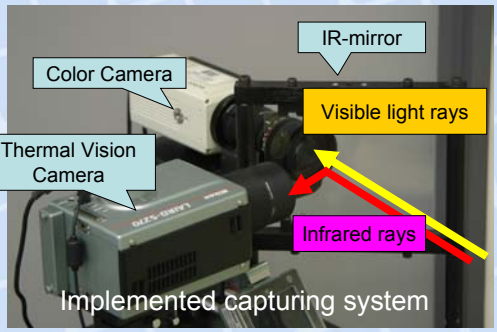
Comparison of related works

Method	Category	Restriction	Target
Chroma-Key (Ultimatte)	Active (lighting)	Blue screens	Mainly human
Background Subtraction	Passive	Static Background	Any objects
Depth-Key	Active is better	Standing position	Any objects
Thermo-Key	Passive	The person must be alive.	Mainly human

Implementation (1)

- A set of a color image and a thermal image should be an identical scene. This means that the same scene should be captured from the same viewpoint at the same time.
- For this purpose, we have implemented a capturing system using a infrared-ray mirror.

Implementation (2)

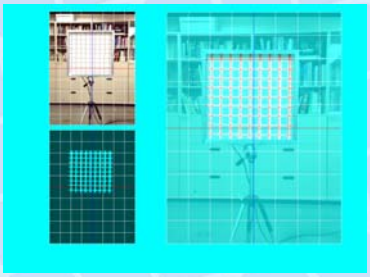


Implementation (3)

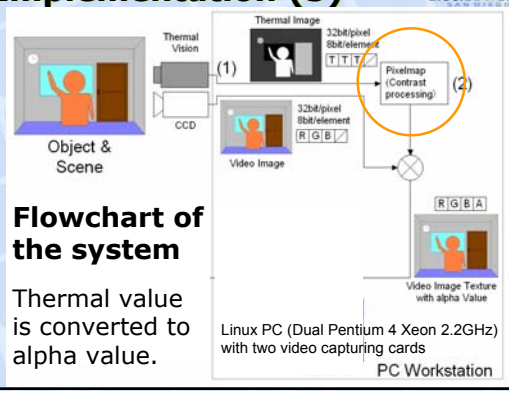
An example of captured images

Implementation (4)

- For the calibration of two cameras, a grid of heat wires is used.



Implementation (5)

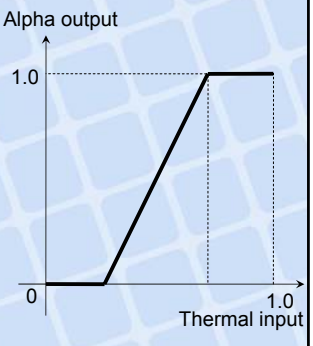


Flowchart of the system

Thermal value is converted to alpha value.

Implementation (6)

- Pixelmap technology controls the conversion from thermal to alpha.
- This makes our system robust for several temperature conditions.
- We can control the contrast and transparency of synthetic image interactively.



Terminology

- Hot pixel: a pixel whose thermal data has higher value (hot pixels are bright in thermal image)
- Cool pixel: a pixel whose thermal data has lower values (cool pixels are dark in thermal image)

Innovative Visual Effects

- The following 7 visual effects are proposed and implemented here.
  - Temperature-Based Color Control
  - Shadow-Like Effect Creating the Presence of Somebody
  - Interaction Using Cold Objects
  - Interaction Using Warm Objects
  - Opaque for Visible Rays while Transparent for Infrared Rays
  - Superimposing on the Same Scene
  - Taking a Set of Your Snapshots

Innovative Visual Effects 1: Temperature-Based Color Control

Examples:
"Only You Are Monochrome"
"Only You Are Colorful"

Color Control (1)

- This method modulates, converts or controls color values of pixels according to the corresponding thermal data.
- Input data:
  - a color video sequence, and
  - a thermal video sequence corresponding to the color video.

Color Control (2)

- Algorithm:
  We define a function *F*,
  $c_o(\mathbf{p}) = F(c_i(\mathbf{p}), t(\mathbf{p}))$
  where
  - $c_o(\mathbf{p})$: output color value of pixel $\mathbf{p}$
  - $c_i(\mathbf{p})$: input color value of pixel $\mathbf{p}$
  - $t(\mathbf{p})$: input thermal value of pixel $\mathbf{p}$; we consider the case where $0 <= t(\mathbf{p}) <= 1$.

Color Control (3)

- The function *F* is user definable. Some examples are shown here, but the function is not limited to these examples.
  - Example 1:
    $chroma(c_o(\mathbf{p})) = t(\mathbf{p})\ chroma(c_i(\mathbf{p}))$
  - Example 2:
    $chroma(c_o(\mathbf{p})) = (1-t(\mathbf{p}))\ chroma(c_i(\mathbf{p}))$
  - Example 3:
    $chroma(c_o(\mathbf{p})) = 0$
    when $t(\mathbf{p}) <= threshold$
    $chroma(c_o(\mathbf{p})) = chroma(c_i(\mathbf{p}))$
    when $t(\mathbf{p}) > threshold$

Color Control (4)

- The following 2 pages contain results of this visual effect.
  - Only You Are Monochrome:
    - Hot pixels are converted into monochrome, while cool pixels remain colorful.
  - Only You Are Colorful:
    - Cool pixels are converted into monochrome, while hot pixels remain colorful.
- We can do this because we don't use a blue screen used in chroma-keying.

Color Control (5)
Only You Are Monochrome

Hot pixel: monochrome
Cool pixel: colorful


Color Input


Thermal Input


Result of Real-Time Visual Effect

Color Control (6)
Only You Are Colorful

Hot pixel: colorful
Cool pixel: monochrome


Color Input


Thermal Input


Result of Real-Time Visual Effect

Innovative Visual Effects 2:
Shadow-Like Effect Creating the Presence of Somebody

Examples:
"A Textured Man"
"An Invisible Man"

Shadow-Like Effect (1)

- This method blends or superimposes an image onto a color video input according to the corresponding thermal input.
- Input data:
  - a color video sequence,
  - a thermal video sequence corresponding to the color video, and
  - an image to be superimposed.

Shadow-Like Effect (2)

- Algorithm:
  $c_o(\mathbf{p}) = img(\mathbf{p})$
  when $t(\mathbf{p}) > threshold$ (human region)
  $c_o(\mathbf{p}) = c_i(\mathbf{p})$
  when $t(\mathbf{p}) <= threshold$ (background)
  where
  - $c_o(\mathbf{p})$: output color value of pixel $\mathbf{p}$
  - $c_i(\mathbf{p})$: input color value of pixel $\mathbf{p}$
  - $t(\mathbf{p})$: input thermal value of pixel $\mathbf{p}$
  - $img(\mathbf{p})$:color value of pixel $\mathbf{p}$ on the image to be superimposed

Shadow-Like Effect (3)

- This effect looks like an inversion of the superimposing method based on chroma-keying. This means that only human region is changed while the background region is not changed.
- We can create the presence of somebody without showing who he/she is. This means that personal privacy is protected.

Shadow-Like Effect (4)
A Textured Man

Results of Real-Time Visual Effect

Shadow-Like Effect (5)

- Consider the case where the image *img(**p**)* is a picture of the scene captured before the human enters the scene. In the synthesized image, the human looks like an invisible man because of the following condition.
  - background region: current scene
  - human region: previously captured scene
- By combining the "temperature-based color control" effect, we can see such images as shown in the next slide.

Shadow-Like Effect (6)
An Invisible Man

Results of Real-Time Visual Effect

Innovative Visual Effects 3:
Interaction Using Cold Objects

Examples:
"Disappear from the Virtual World"
"Partially Colorful"
"Partially Invisible"
"Vanish Behind a Cloak"

Using Cold Objects (1)

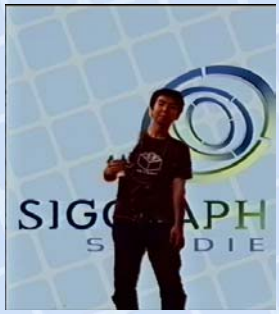
- Algorithm:
  $c_o(\mathbf{p}) = c_i(\mathbf{p})$
  when $t(\mathbf{p}) > threshold$ (human)
  $c_o(\mathbf{p}) = img(\mathbf{p})$
  when $t(\mathbf{p}) <= threshold$ (background)
  where
  - $c_o(\mathbf{p})$: output color value of pixel **p**
  - $c_i(\mathbf{p})$: input color value of pixel **p**
  - $t(\mathbf{p})$: input thermal value of pixel **p**
  - $img(\mathbf{p})$:color value of pixel **p** on the background image (the virtual world)

Using Cold Objects (2)

- If you have something cold in your hand or in front of you, its region is treated as low temperature region, in other words, background region.
- You can prevent something hot in the real world from appearing in the virtual world by placing a cold object in front of the hot object.
- Even if the cold object is transparent, it works.

Using Cold Objects (3)
Disappear from the Virtual World (1)



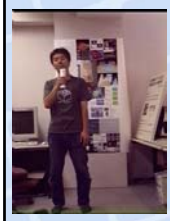
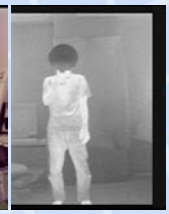


Color Input **Thermal Input**

He has a cold transparent acrylic plate

Result of Real-Time Visual Effect

Using Cold Objects (3)
Disappear from the Virtual World (2)


Color Input **Thermal Input**

He has a cold transparent acrylic plate

Result of Real-Time Visual Effect

Using Cold Objects (3)
Disappear from the Virtual World (3)



Color Input **Thermal Input**

He has a cold transparent acrylic plate

Result of Real-Time Visual Effect

Using Cold Objects (4)

- By combining the "temperature-based color control" effect, we can see such images as shown in the following 6 slides.

Using Cold Objects (5)
Partially Colorful (1)

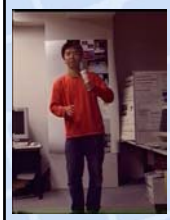


Color Input **Thermal Input**

He has a cold transparent acrylic plate

Result of Real-Time Visual Effect

Using Cold Objects (5)
Partially Colorful (2)



Color Input **Thermal Input**

He has a cold transparent acrylic plate

Result of Real-Time Visual Effect

Using Cold Objects (5)
Partially Colorful (3)



Color Input **Thermal Input**

He has a cold transparent acrylic plate

Result of Real-Time Visual Effect

Using Cold Objects (5)
Partially Colorful (4)



Color Input **Thermal Input**

He has a cold transparent acrylic plate

Result of Real-Time Visual Effect

Using Cold Objects (5)
Partially Colorful (5)



Color Input **Thermal Input**

He has a cold transparent acrylic plate

Result of Real-Time Visual Effect

Using Cold Objects (5)
Partially Colorful (6)



Color Input **Thermal Input**

He has a cold transparent acrylic plate

Result of Real-Time Visual Effect

Using Cold Objects (6)

- Consider the case where the image *img(**p**)* is a picture of the scene captured before the human enters the scene. We have the following condition.
  - background: previously captured scene
  - human region: current scene
- By placing a cold object in front of you, you can be partially invisible. This means that the previously captured scene appears in a part of your body region.

Using Cold Objects (7)
Partially Invisible (1)



Color Input **Thermal Input**

He has a cold transparent acrylic plate

Result of Real-Time Visual Effect

Using Cold Objects (7)
Partially Invisible (2)


Color Input Thermal Input

He has a cold transparent acrylic plate

Result of Real-Time Visual Effect

Using Cold Objects (7)
Partially Invisible (3)


Color Input Thermal Input

He has a cold transparent acrylic plate

Result of Real-Time Visual Effect

Using Cold Objects (7)

- This is not limited to a transparent acrylic plate.
- If you use a transparent cold cloak, you can vanish from the synthesized image by placing the cloak in front of you.

Using Cold Objects (8)
Vanish Behind a Cloak (1)


Color Input Thermal Input

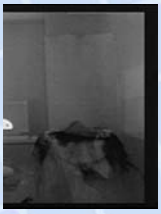
Result of Real-Time Visual Effect

Using Cold Objects (8)
Vanish Behind a Cloak (2)


Color Input Thermal Input

Result of Real-Time Visual Effect

Using Cold Objects (8)
Vanish Behind a Cloak (3)

Color Input Thermal Input

Result of Real-Time Visual Effect

Using Cold Objects (8)
Vanish Behind a Cloak (4)


Color Input Thermal Input

Result of Real-Time Visual Effect

Innovative Visual Effects 4:
Interaction Using Warm Objects

Examples:
"Taking Something into the Virtual World"

Using Warm Objects (1)

- If you have something hot in your hand, its region is treated as a high temperature region, in other words, human region to be segmented.
- You can take something cold in the real world into the virtual world by placing a hot transparent object in front of the cold object.
- This could be regarded as a special lens that transfer the real world to the virtual.

Using Warm Objects (2)
Taking Something into the Virtual World (1)


Color Input Thermal Input

He has a hot transparent acrylic plate

Result of Real-Time Visual Effect

Using Warm Objects (2)
Taking Something into the Virtual World (2)


Color Input Thermal Input

He has a hot transparent acrylic plate

Result of Real-Time Visual Effect

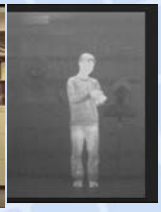
Using Warm Objects (2)
Taking Something into the Virtual World (3)


Color Input Thermal Input

He has a hot transparent acrylic plate

Result of Real-Time Visual Effect

Using Warm Objects (2)
Taking Something into the Virtual World (4)

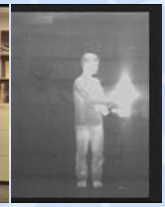




Color Input **Thermal Input**

Fire is also useful for this purpose

Result of Real-Time Visual Effect

Using Warm Objects (2)
Taking Something into the Virtual World (5)

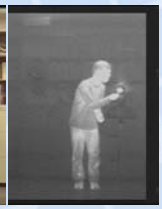




Color Input **Thermal Input**

Fire is also useful for this purpose

Result of Real-Time Visual Effect

Using Warm Objects (2)
Taking Something into the Virtual World (6)


Color Input **Thermal Input**

Fire is also useful for this purpose

Result of Real-Time Visual Effect

Innovative Visual Effects 5:
Opaque for Visible Rays while Transparent for Infrared Rays

Example:
"Balloon Masking"

Opaque for Visible, Transparent for Infrared (1)

- An acrylic plate used in the previous section is transparent for visible rays, but opaque for infrared rays.
- A balloon is very different from the acrylic plate. Its characteristic is as follows:
  - Opaque for visible rays
  - Transparent for infrared rays.
- We will have a balloon-colored human-shaped region as shown in the following 4 slides.

Transparent for Infrared (1)
Balloon Masking (1)



Color Input **Thermal Input**

Result of Real-Time Visual Effect

Transparent for Infrared (1)
Balloon Masking (2)


Color Input


Thermal Input


Result of Real-Time Visual Effect

Transparent for Infrared (1)
Balloon Masking (3)


Color Input


Thermal Input


Result of Real-Time Visual Effect

Transparent for Infrared (1)
Balloon Masking (4)


Color Input


Thermal Input


Result of Real-Time Visual Effect

Innovative Visual Effects 6:
Superimposing on the Same Scene

Example:
"Fight with Yourself"

Superimposing on the Same Scene (1)

- You can superimpose your segmented image onto the same scene.
- By controlling the size and position of your segmented image, you can fight with yourself.

On the Same Scene (2)
Fight with Yourself (1)

On the Same Scene (2)
Fight with Yourself (2)

On the Same Scene (2)
Fight with Yourself (3)

Innovative Visual Effects 7:
Taking a Set of Yourself Snapshots

Example:
"Surrounded by Yourself"

Your Snapshots (1)

- This is not limited to Thermo-key, but available for Chroma-key.
- The segmented region can be regarded as your snapshot. By placing such snapshots on an image, you will have a lot of yourself.

Your Snapshots (2)
Surrounded by Yourself (1)

Your Snapshots (2)
Surrounded by Yourself (2)

Your Snapshots (2)
Surrounded by Yourself (3)

Your Snapshots (2)
Surrounded by Yourself (4)

Your Snapshots (2)
Surrounded by Yourself (5)

Your Snapshots (2)
Surrounded by Yourself (6)

Video 1

Video 2

Video 3

Video 4

Future Work

- Hybrid approaches that utilize color data to overcome the demerits of thermal data
- More compact capturing system
- More applications that cannot be realized by other approaches

History of our project

- 1999.2- Takeshi NAEMURA
- 1999.4- Hiroshi HARASHIMA
- 1999.4-2000.3 Yoshihiro KAWAHARA
- 2000.4-2001.3 Takeshi MATSUSHITA
- 2001.4- Kazutaka YASUDA

- 1999 The first prototype using Onyx
- 2002 The PC-based system you can experience at SIGGRAPH2003

Team Thermo-Key

- Kazutaka YASUDA
- Takeshi NAEMURA
- Makoto IIDA
- Hiroshi DOHI
- Tomoyuki YAMAMOTO
- Satoshi MITSUDA
- Kumiko MORIMURA
- Nahomi MORIMURA

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