Real-Time Computer Vision for Human Interfaces

Yoshio Matsumoto

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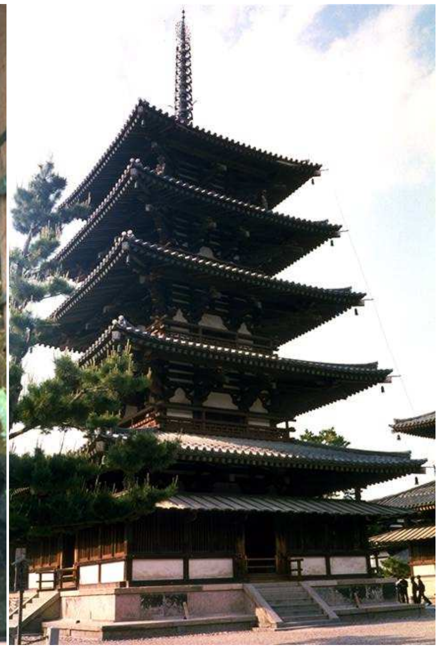
Introduction to Robotics Lab at NAIST



video

Face Measurement System and Its Applications

Yoshio Matsumoto
Nara Institute of Science and Technology, Japan

Motivation: Face Measurement

- For Human-Robot Interaction,
  - when a person teaches a task to a robot
  - when a person makes a cooperative task with a robot

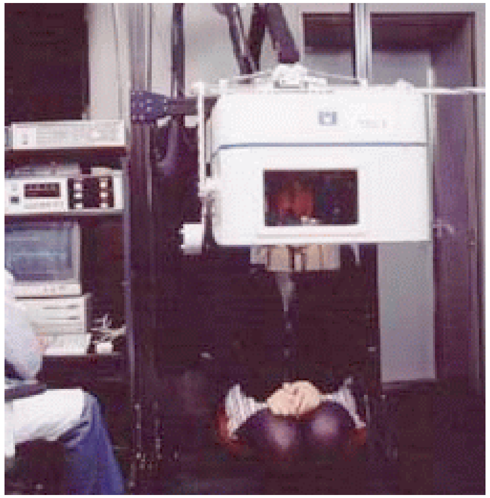
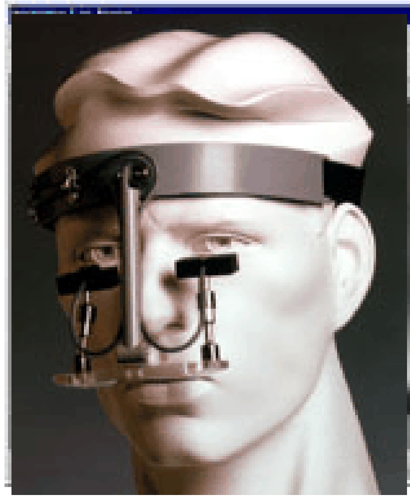
  natural ways of communication is required.
- Head motion and gaze direction reflect intention and attention of a person.

⇩

Goal of this research:

Head Motion	=> Gesture	=>=>=> Intention
Gaze Direction	=> Attention	

Gaze Tracking Techniques: Corneal Reflection


- Head should not move, or head pose is measured by magnetic sensor etc.
- Eye rotation is detected using IR refection on corneal
- Head mounted device prohibits natural behaviors
- Accurate in best condition, however hard to keep it
- Binocular systems and external camera system are also available

Gaze Tracking Techniques: Corneal Reflection (cont'd)

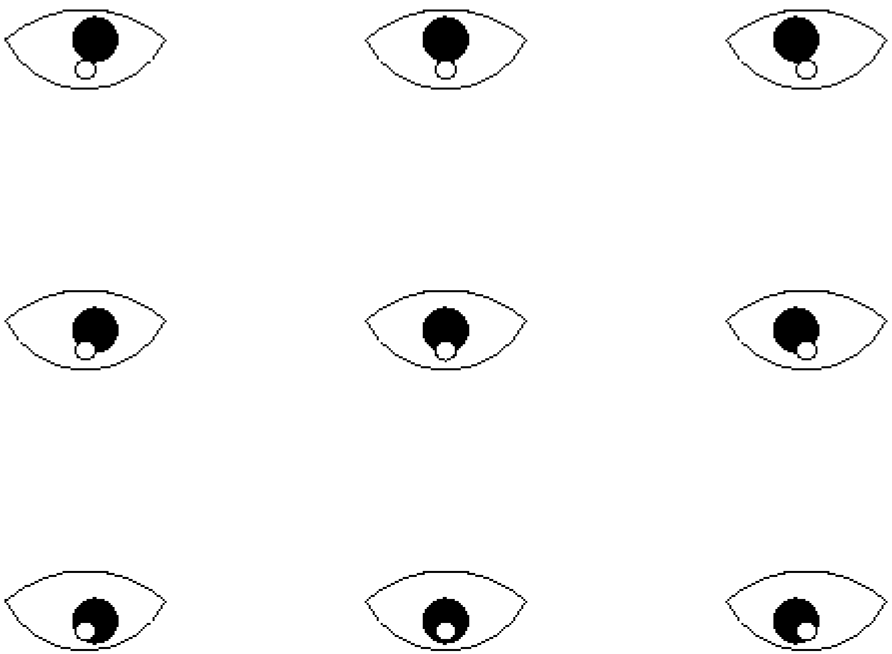


Figure: Pupil and Purkinje images as seen by eye tracker's camera

- Purkinje images appear as small white dots in close proximity to the (dark) pupil
- tracker calibration is achieved by measuring user gazing at properly positioned grid points (usually 5 or 9)
- tracker interpolates POR on perpendicular screen in front of user

Gaze Tracking Techniques: EOG (electro-oculography)

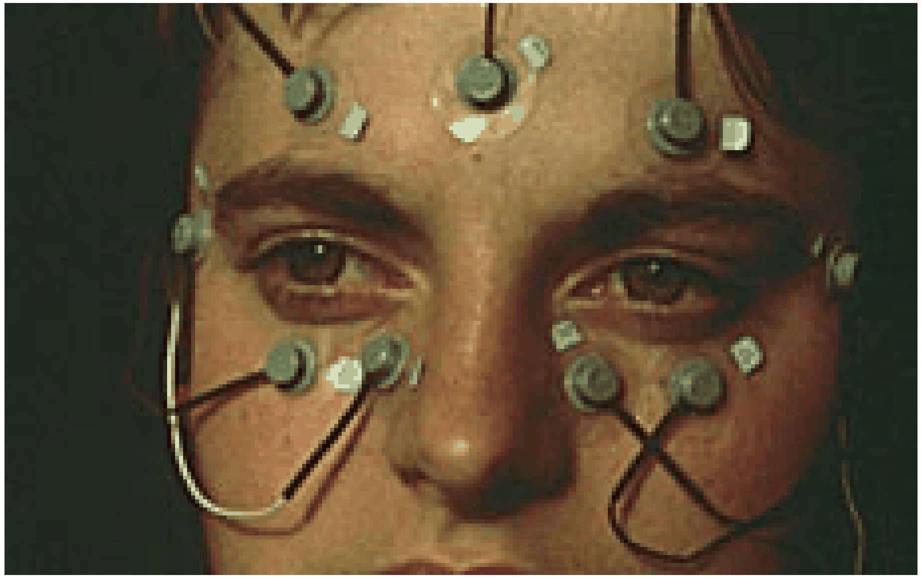
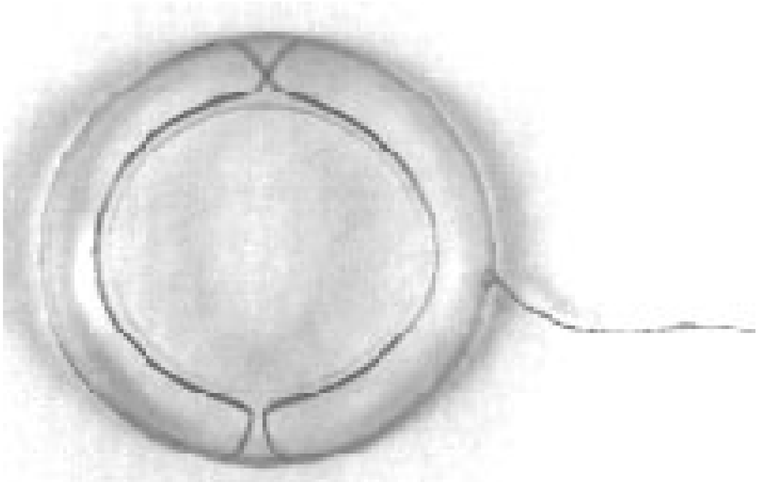


Figure: EOG measurement:

- relies on measurement of skin's potential differences using electrodes placed around the eye

- most widely used method some 20 years ago (still used today)
- measures eye movements relative to head position
- not generally suitable for POR measurement (unless head is also tracked)

Gaze Tracking Techniques: Scleral Contact Lens/Search Coil



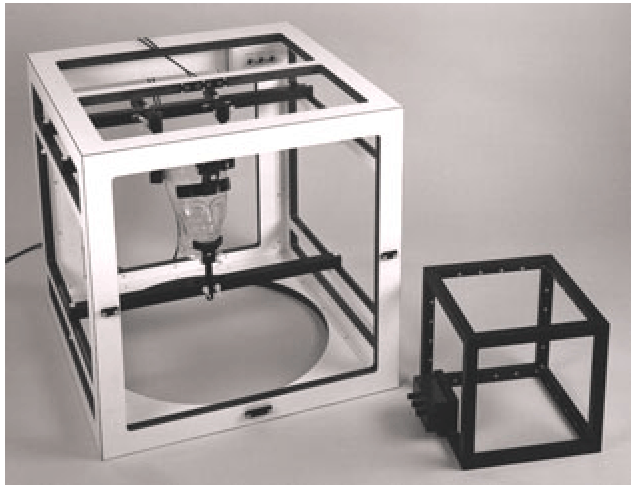


Figure: Scleral coil:

- search coil embedded in contact lens and electromagnetic field frames

- possibly most precise
- similar to electromagnetic position/orientation trackers used in motion-capture

Gaze Tracking Techniques: Scleral Contact Lens/Search Coil (cont'd)

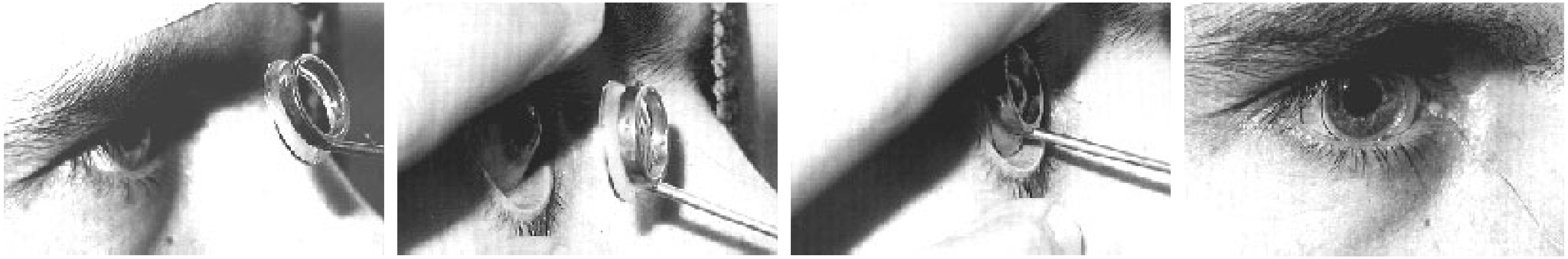


Figure: Example of scleral suction ring insertion:

- most intrusive method
- insertion of lens requires care
- wearing of lens causes discomfort

- highly accurate, but limited measurement range (~5°)
- measures eye movements relative to head position
- not generally suitable for POR measurement (unless head is also tracked)

Real-Time Vision for Face Measurement

Toyama, MSR (1998)

Colmenarez, UIUC (1997)

- One of the important topics in PUI research
- Being actively studied at Microsoft, IBM, MIT, CMU, Univ. of Illinois etc.

- Few of them can measure the quantitative gaze direction
- Most of them use monocular camera systems

Our Approach

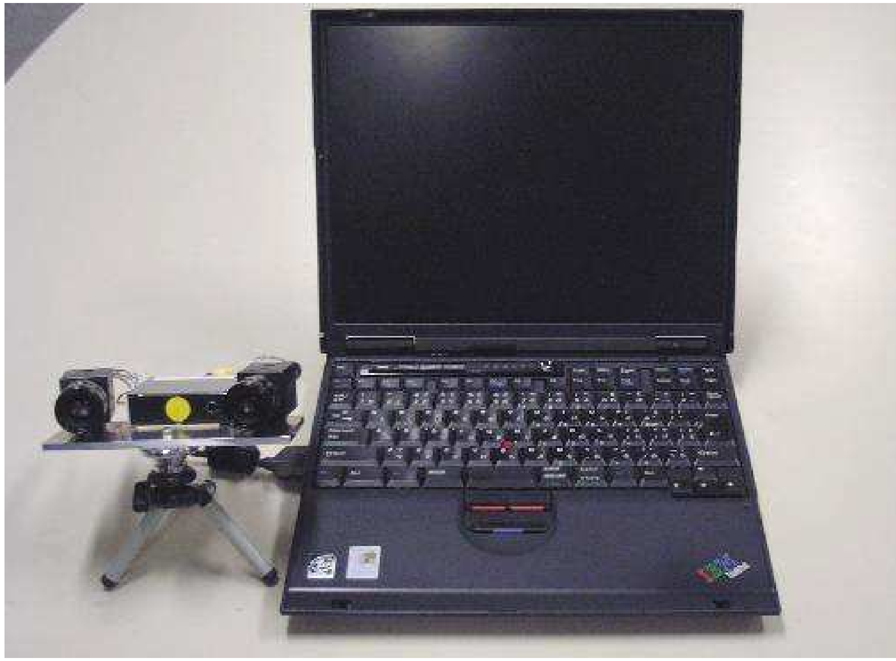
- Stereo camera system for 3D measurement
- 3D facial model
- Feature tracking by normalized correlation
- 3D model fitting algorithm based on spring model

- Real-time Face Tracking
- Gaze direction, blinking and lip motion are additionally measured

1. Algorithm of Face Measurement

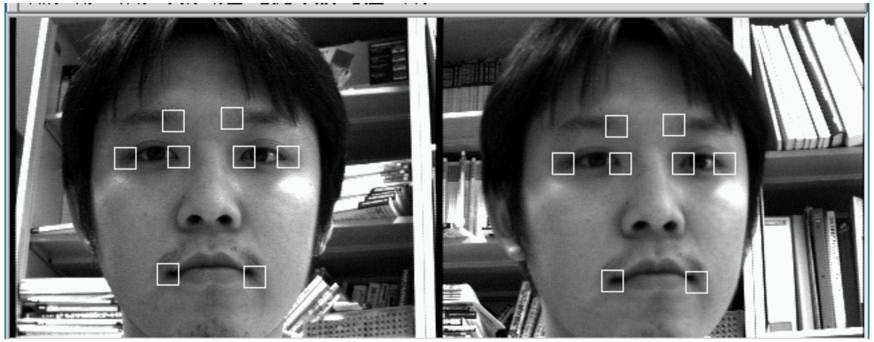
System Configuration

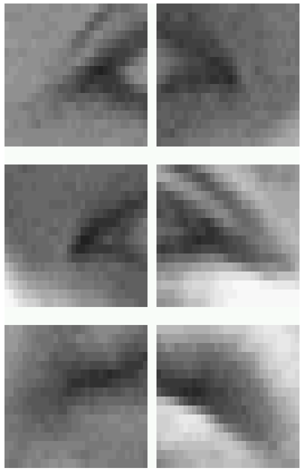
- PC with Pentium III 450MHz or higher
- OS : Linux 2.2 or 2.4
- Stereo Camera Pair



3D Facial Model

- Corners of eyes and mouth are used for tracking
- 3D Facial Model = Template Images + 3D coordinates



Template image for feature tracking	3D coordinates of features	Template image of whole face
	(−50.7, 13.4, −4.2) (−18.2, 12.8, −1.9) (16.1, 12.8, −2.1) (48.0, 11.0, −10.8) (−25.9, −58.7, 10.1) (27.6, −58.6, 4.5)	

3D Model Fitting for Face Tracking

$$E = \sum_{i=0}^{n-1} W_i (Rx_i + t - y_i)^T (Rx_i + t - y_i)$$

n : # of features
x_i : Coordinate of each feature in the model
y_i : Coordinate of each measurement
W_i: Reliability for each measurement (0 ..1)

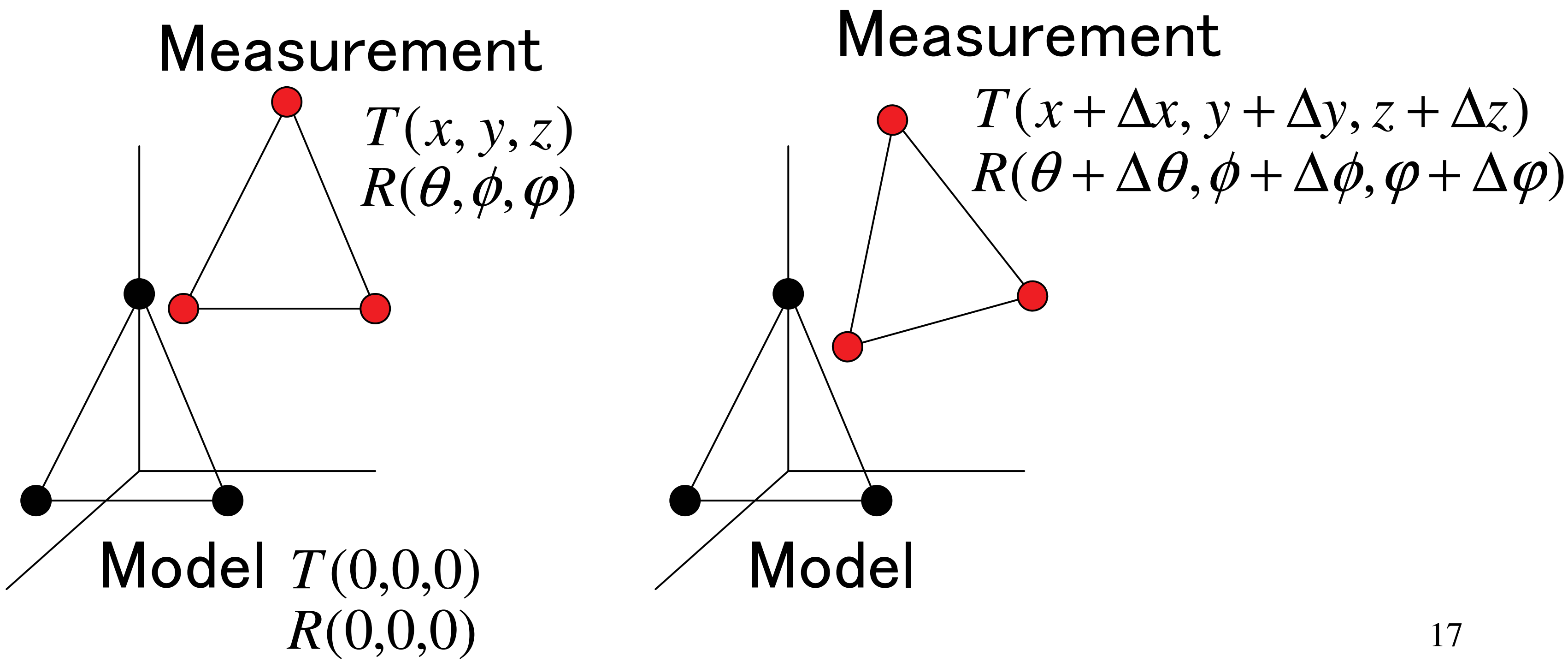
⇩ Minimizing E

$R(\theta, \phi, \varphi)$: Rotation matrix
$T(x, y, z)$: Translation vector

3D Model Fitting for Face Tracking
(cont'd)

Assumption: displacement between previous and current frame is small

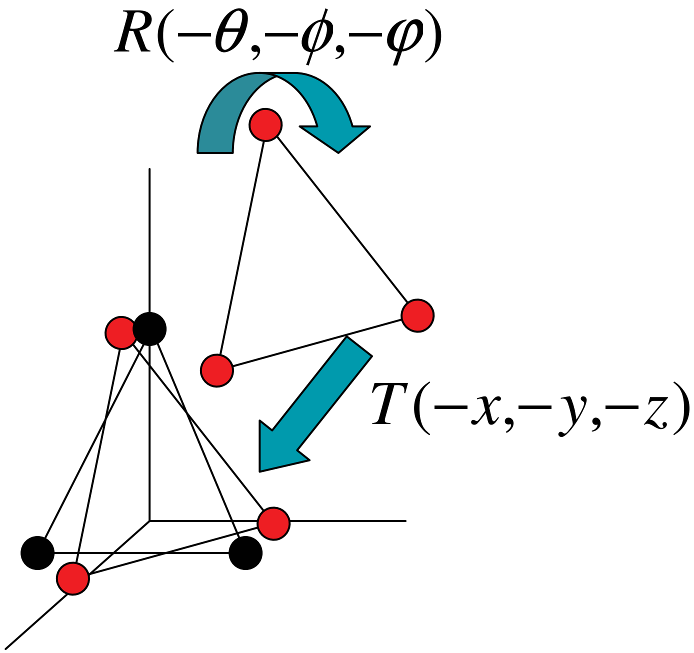
At time t	At time $t + dt$



3D Model Fitting for Face Tracking
(cont’d)

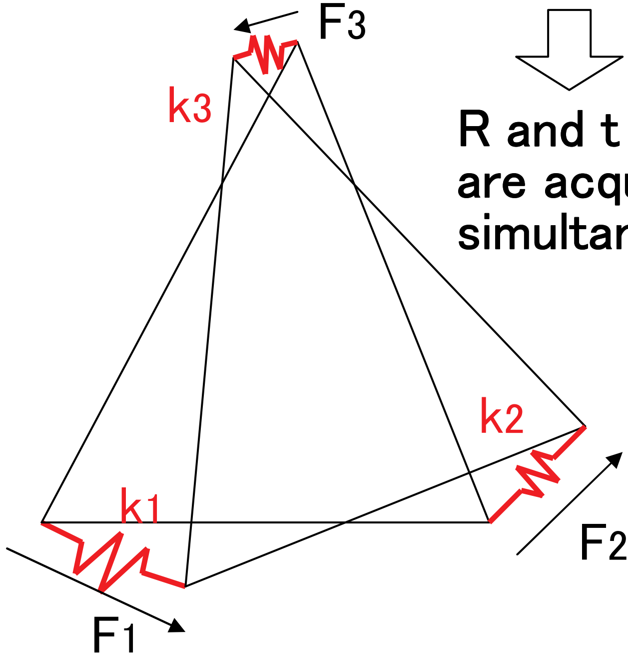
Gradient 3D model fitting method
based on virtual spring model

At time $t + dt$



Displacement dut to $(\Delta\theta, \Delta\phi, \Delta\varphi)$
and $(\Delta x, \Delta y, \Delta z)$ still remains

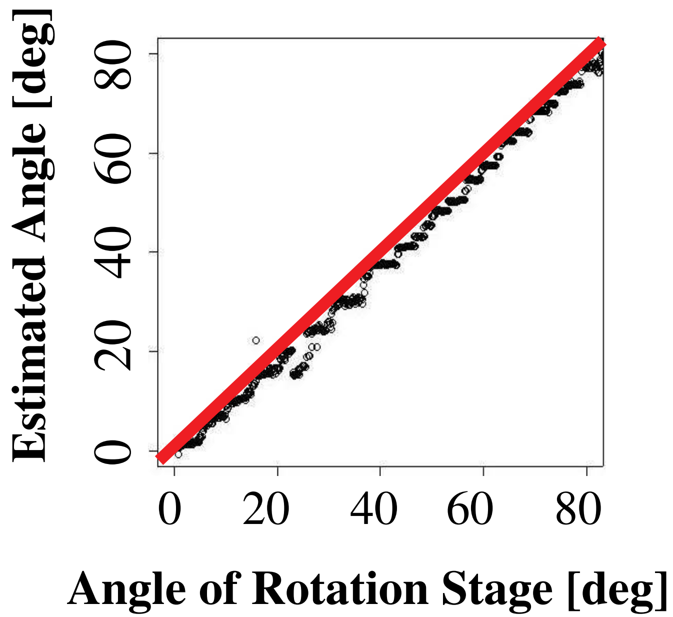
Stiffness of spring k_i = W_i (Reliability)



R and t
are acquired
simultaneously

Result of Face Tracking

Accuracy of Face Tracking



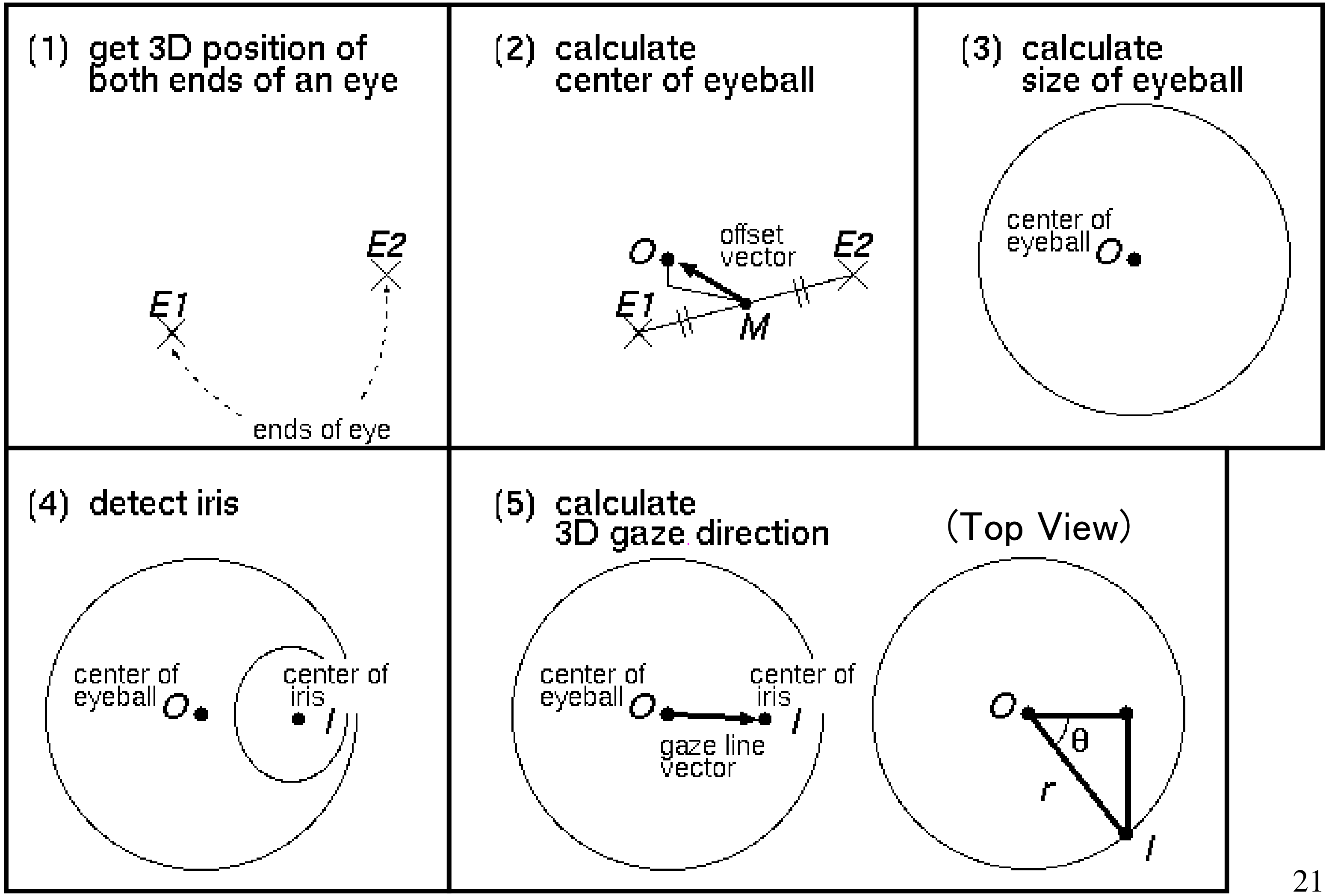
Measurable Range

Roll :-35～+35[deg]
Pitch :-80～+80[deg]
Yaw :-35～+35[deg]

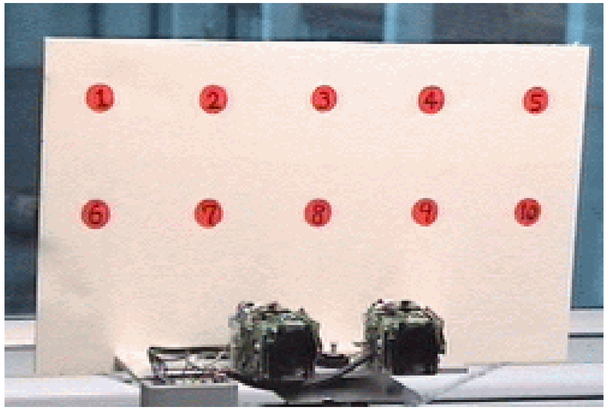
Accuracy

Approx. 2[deg]

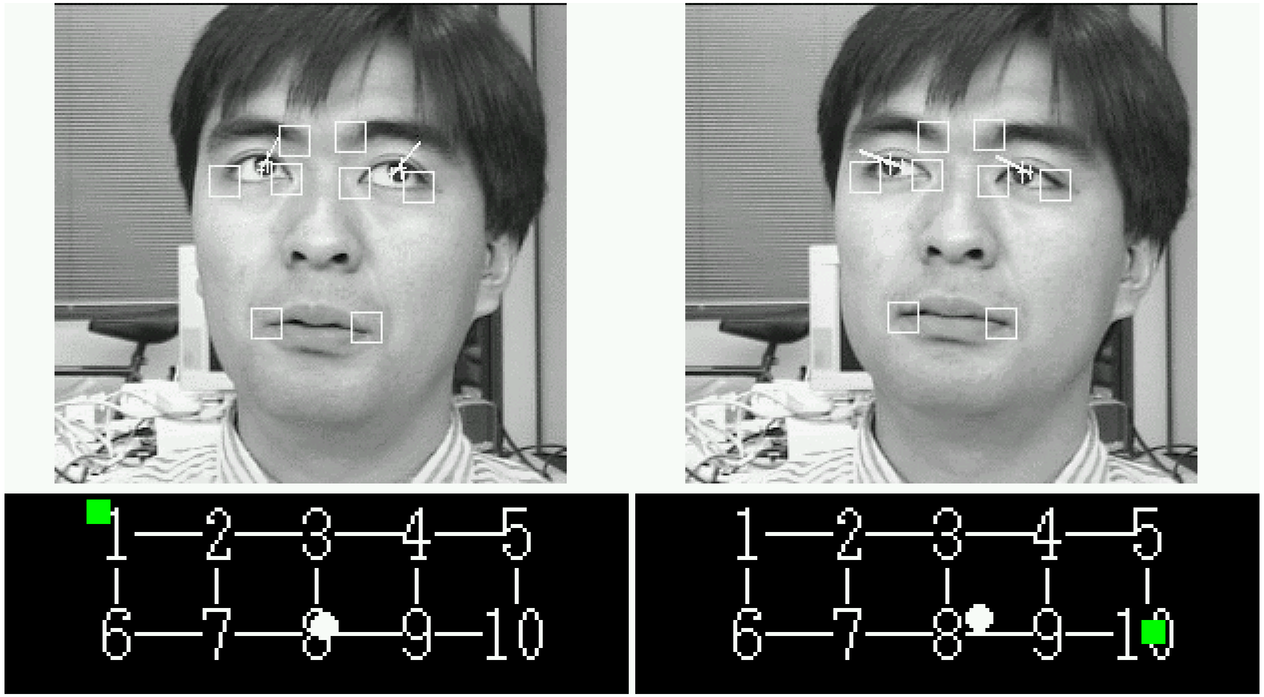
Estimation of Gaze Direction



Result of Gaze Measurement

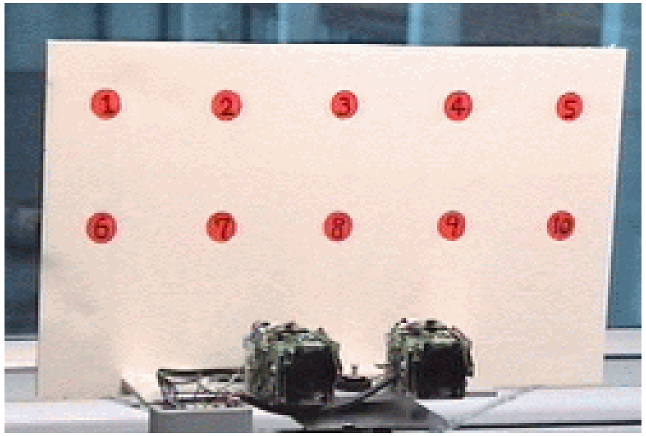


- Look at markers from ① to ⑩ with intervals of 10cm
- Intersection of 3D gaze vector and the board are displayed as a fixation point

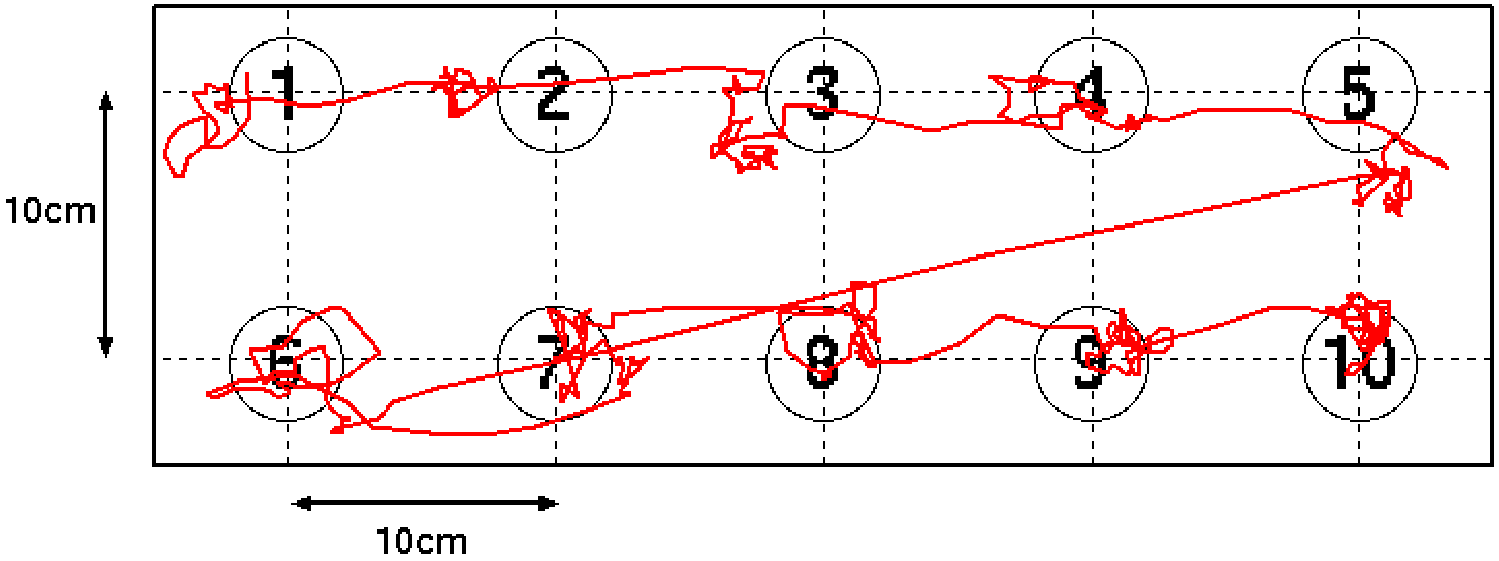


Result of Gaze Measurement

Result of Gaze Measurement



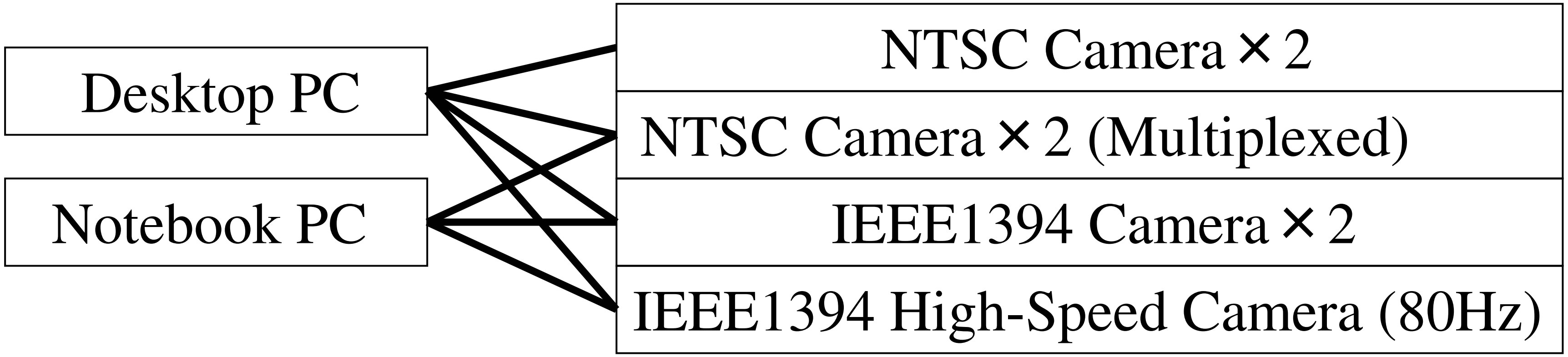
Accuracy: Approx. 5[deg]



Result of Face Measurement

Hardware Configuration

Selectable from below combinations
depending on requirements and costs

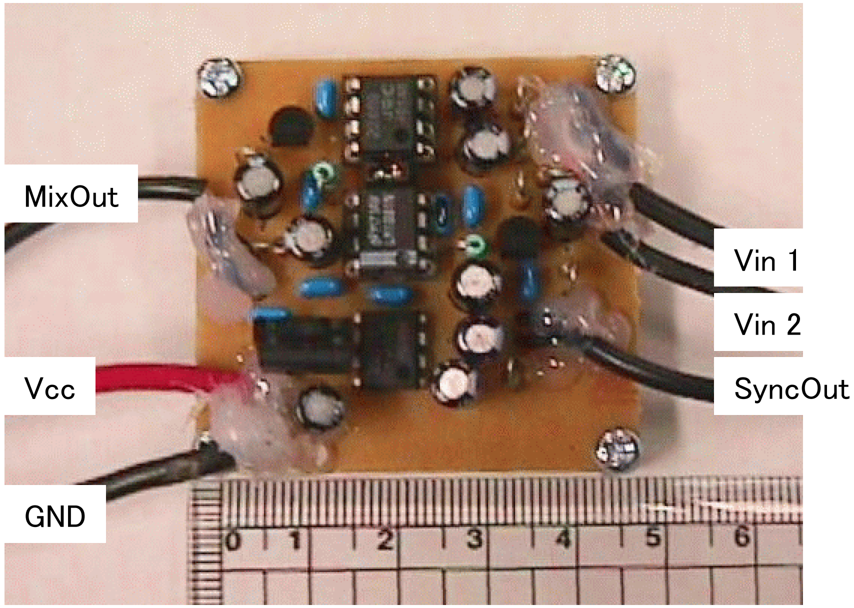


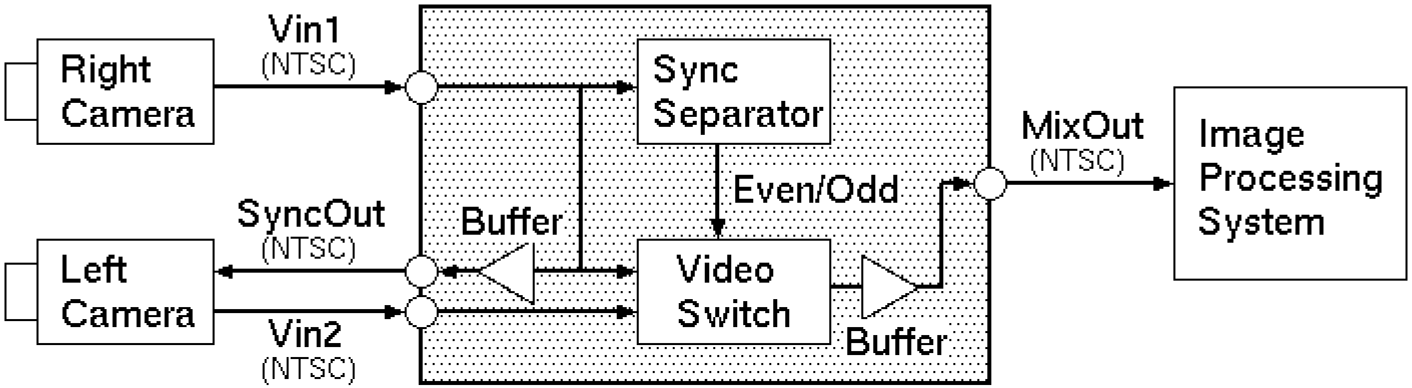
IEEE1394 High-Speed Stereo Camera, 80Hz

30Hz, 1.5kg, US$2000

Field Multiplexing Device

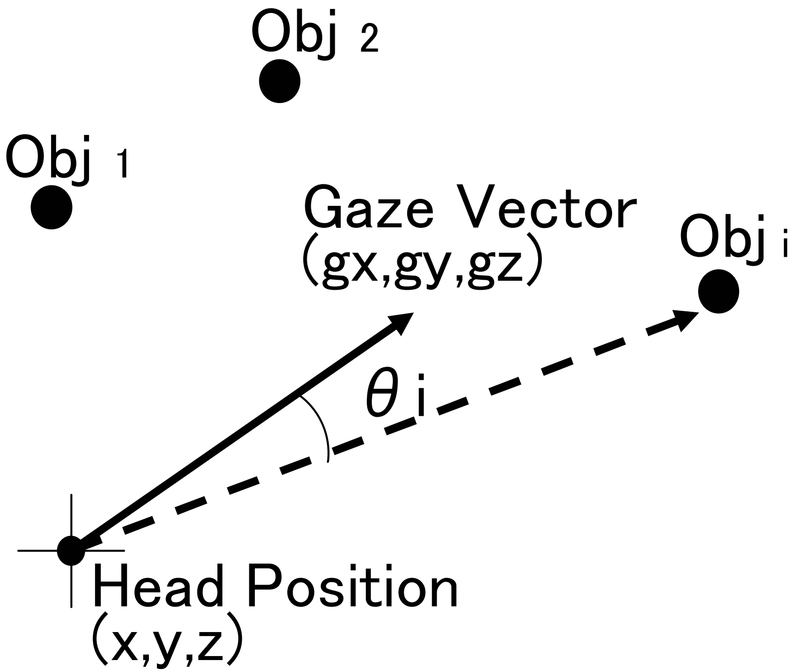
- Multiplexed stereo video streams into a single video stream.
- Vertical resolution of each video signal becomes half.
- Can be used for any conventional image processing system.

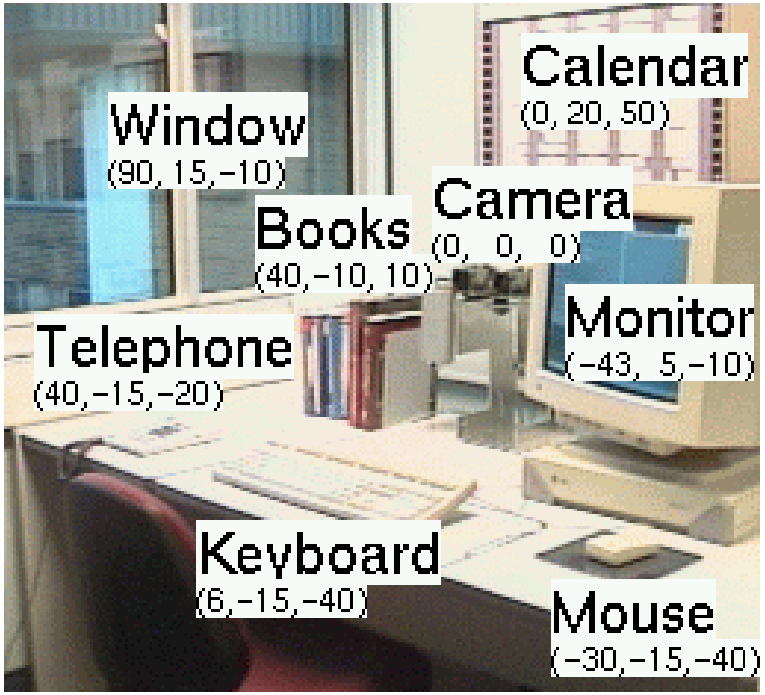




Attention Recognition

The object that a person is looking at is recognized by calculating θi for all objects.



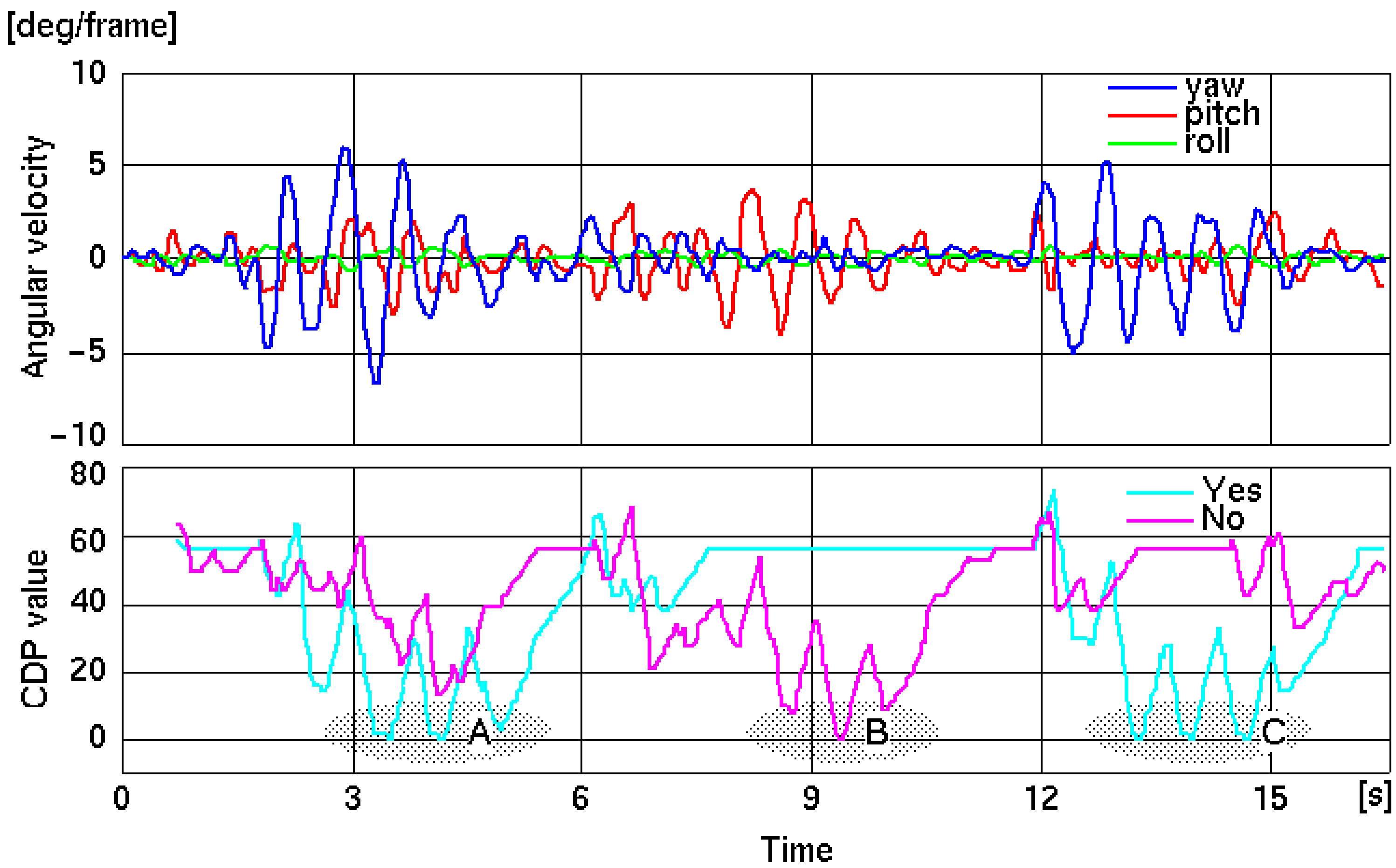


Attention Recognition

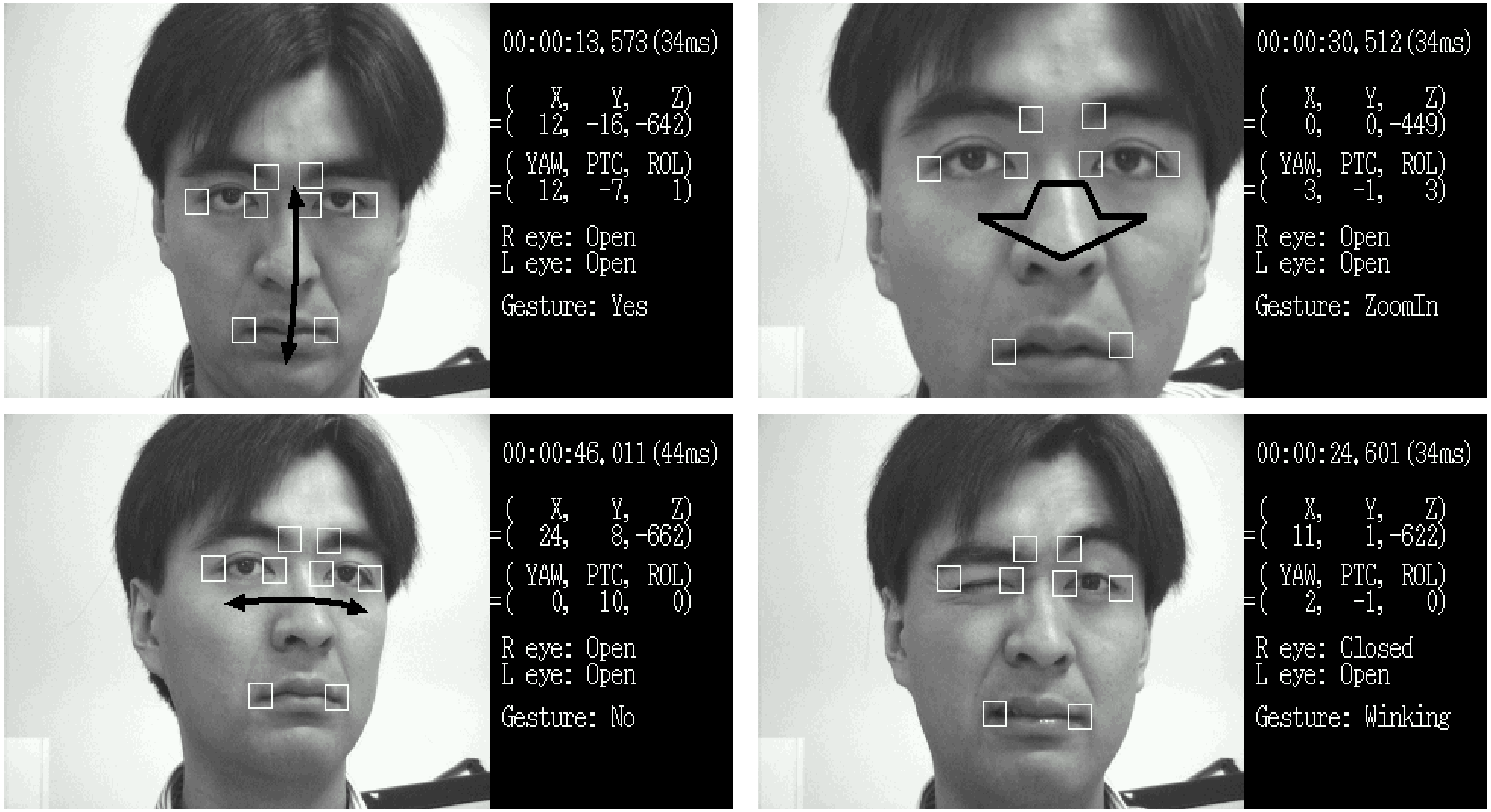
Attention Recognition

Gesture Recognition

Spotting gesture recognition based on Continuous DP Matching using head motions (velocity, angular velocity)



Gesture Recognition



Gesture Recognition

Specs of Developed System

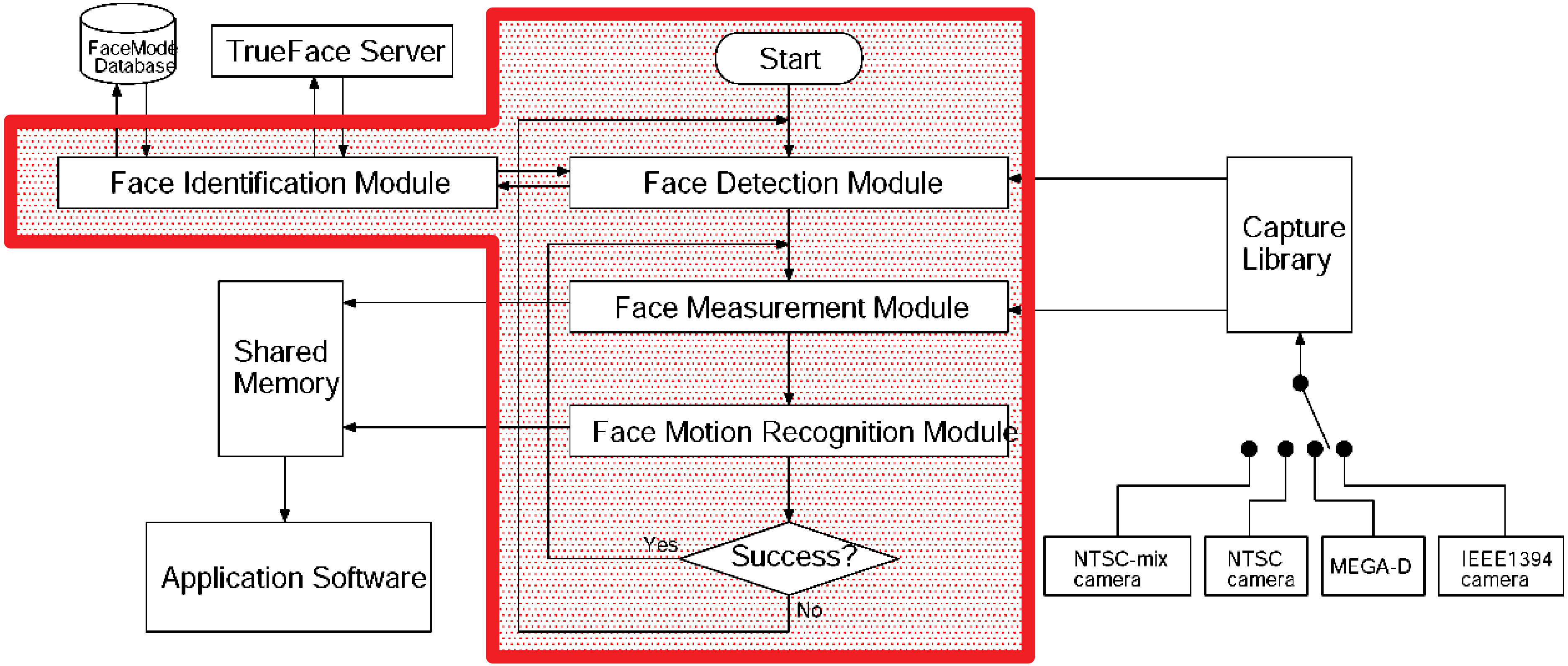
Accuracy

Head pos : 2mm
dir : 2deg
Gaze dir : 5deg

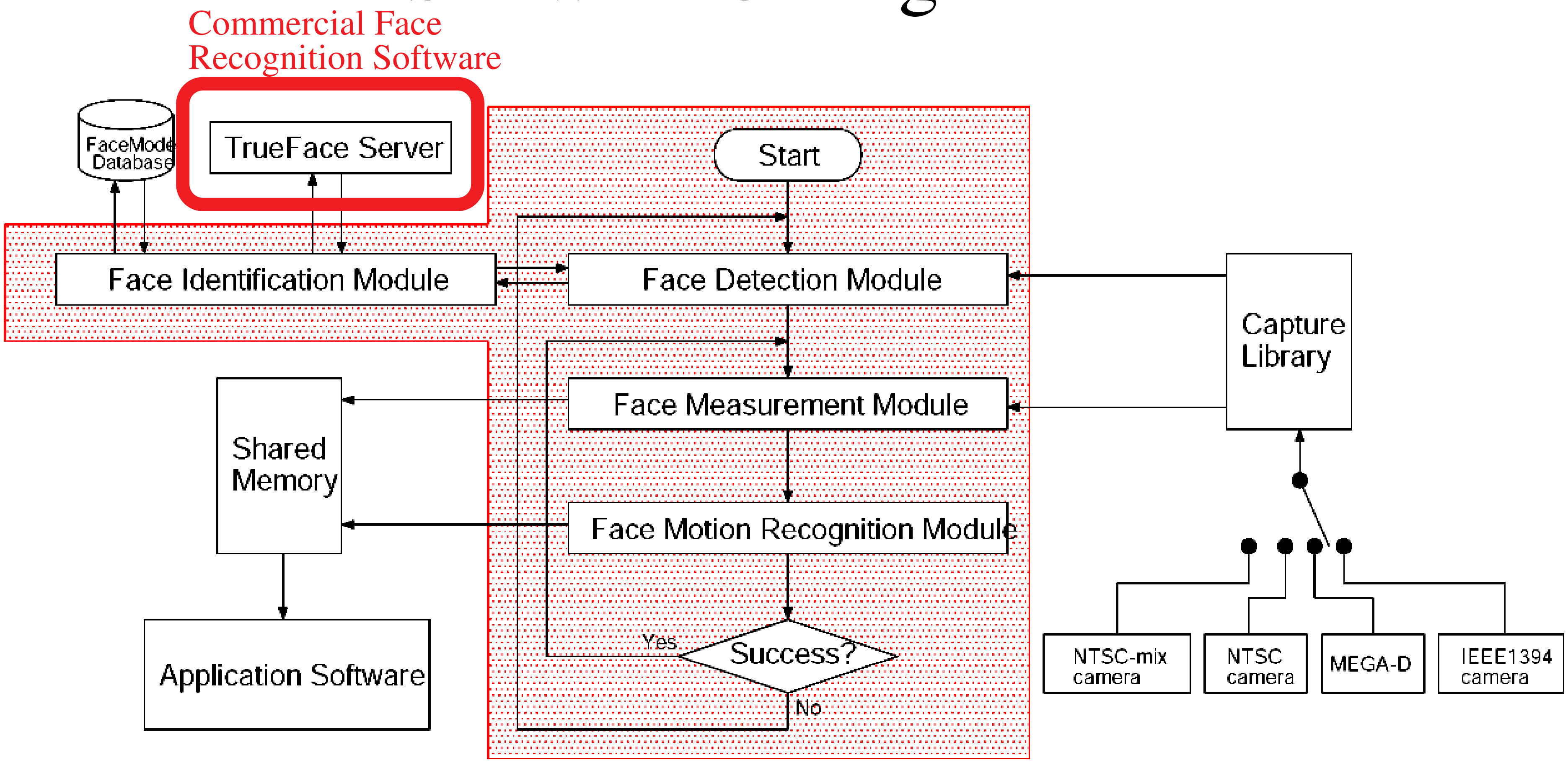
Processing Speed

30Hz～80Hz
(depending on camera)

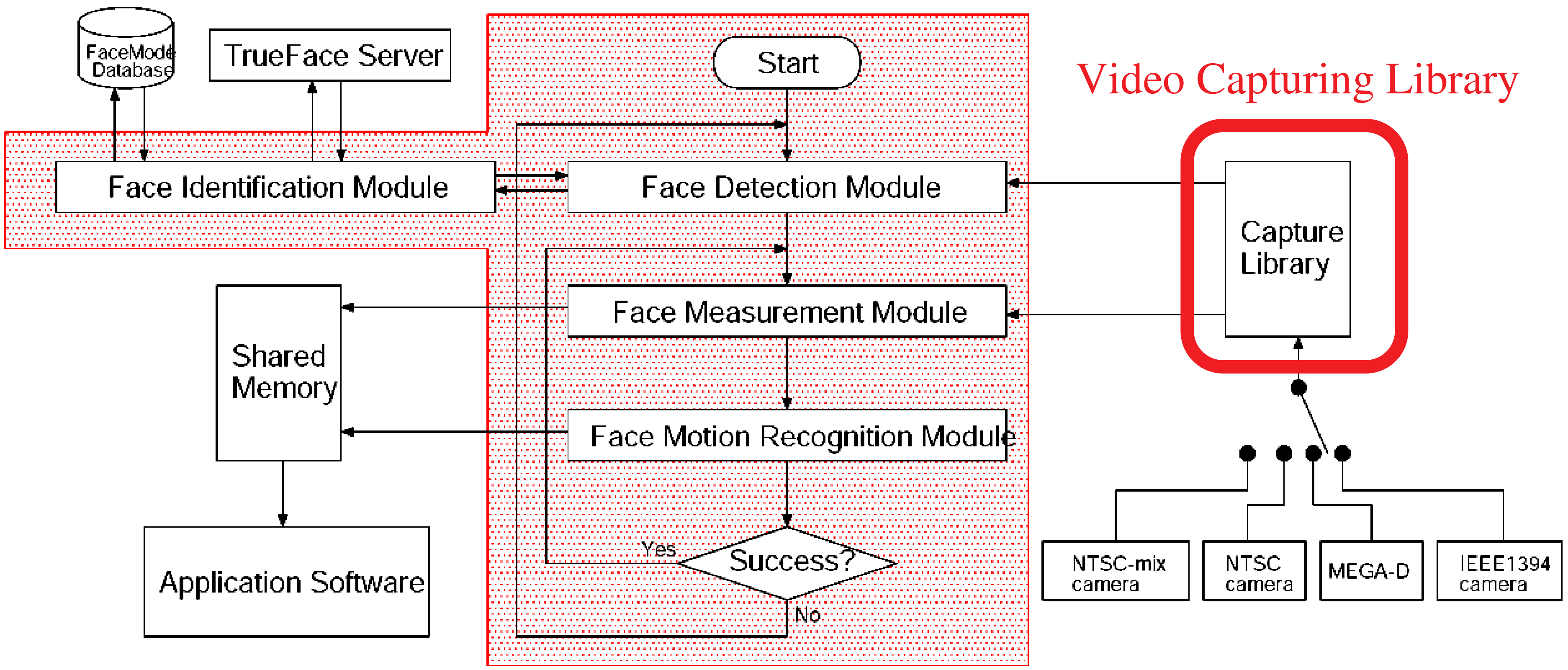
Software Configuration



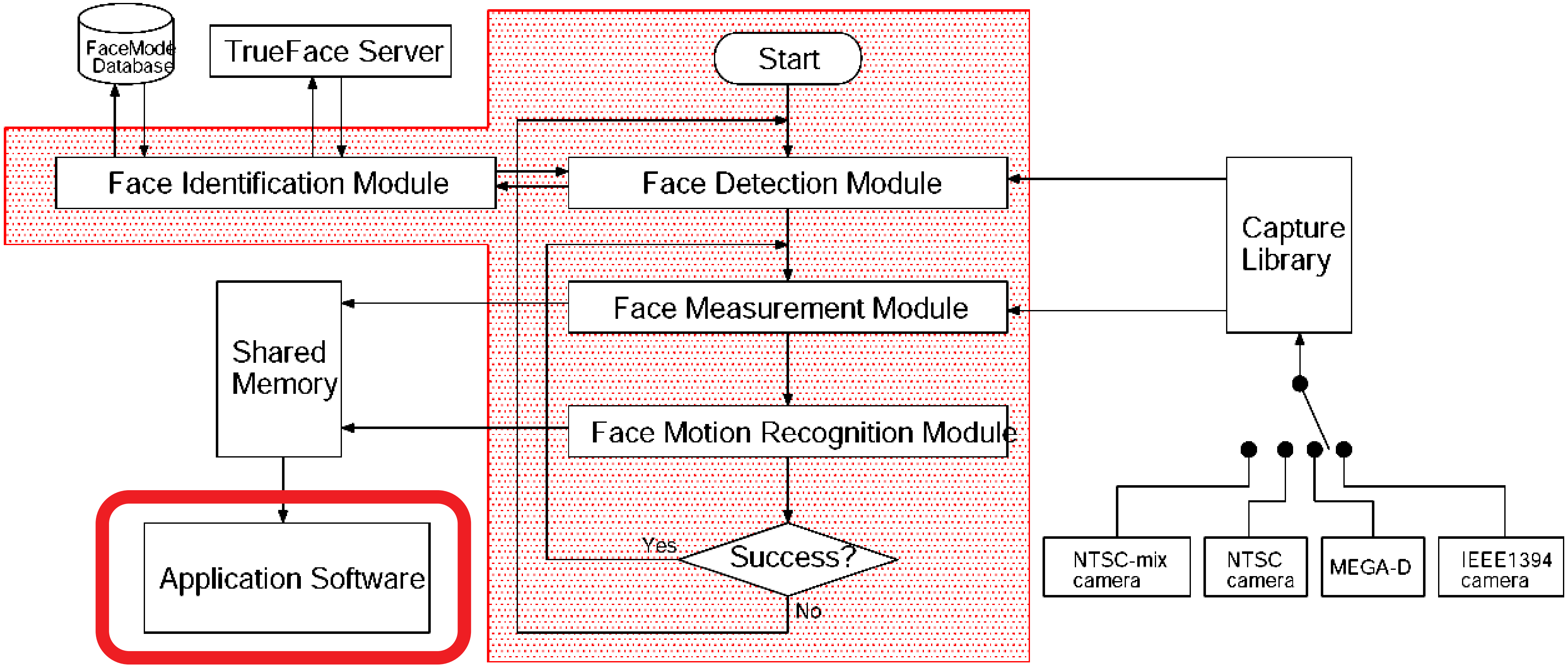
Software Configuration



Software Configuration



Software Configuration



Application Software

Potential Application Areas

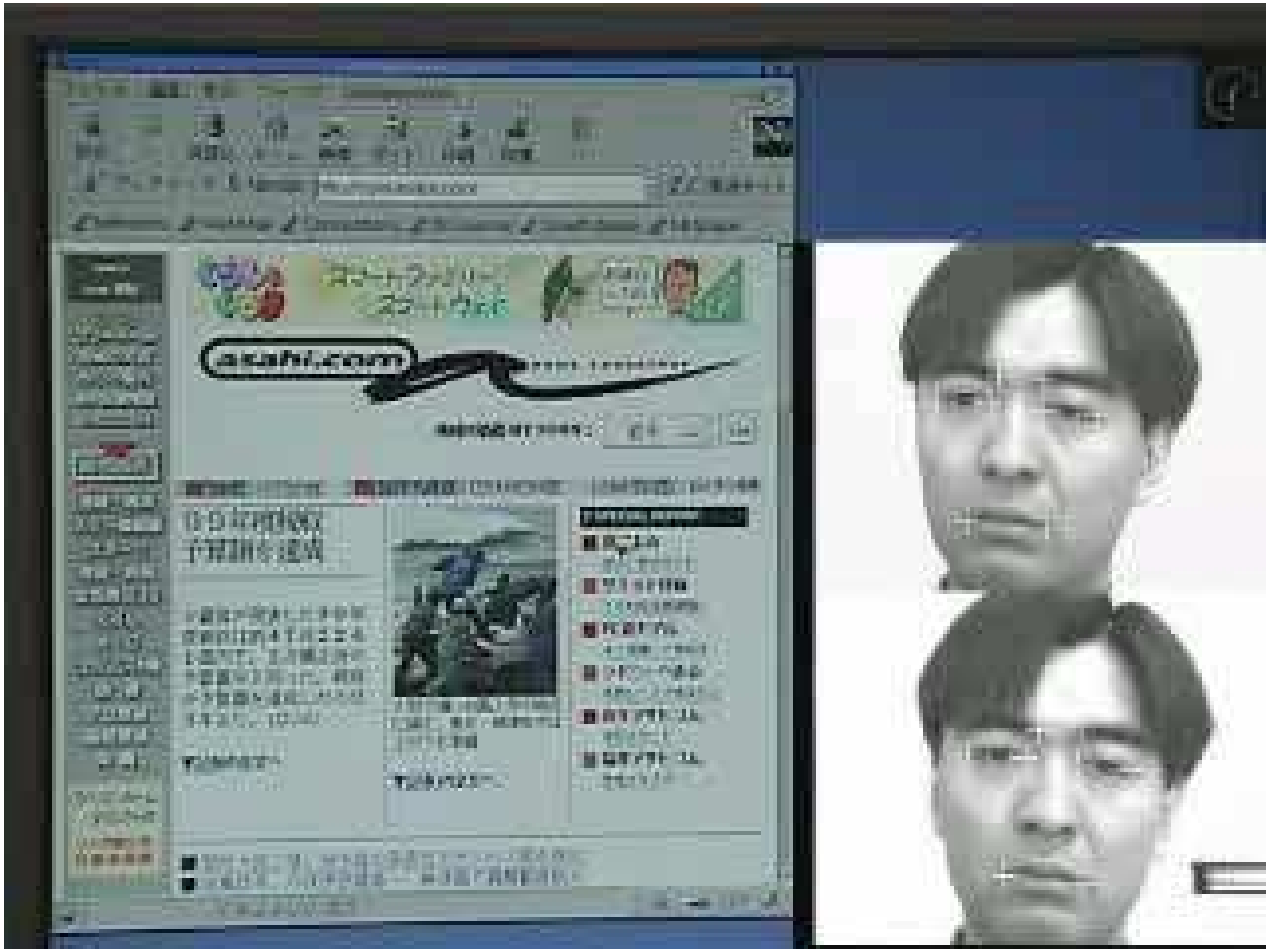
Since this system is non-contact, passive, and inexpensive, it can be applied to many application areas where conventional systems cannot be used.

- Human Interfaces
  - Computer Interface（e.g. Hands-free mouse）
  - Robot Interface（e.g. Eye-contact communication）
  - Safety System（e.g. Driver support）
  - Assistive Products for the disabled
- Human Modeling
  - Cognitive Science (Experiment on visual cognition）
  - Ergonomics（e.g. Human-friendly design)

2. Application to Human Interfaces

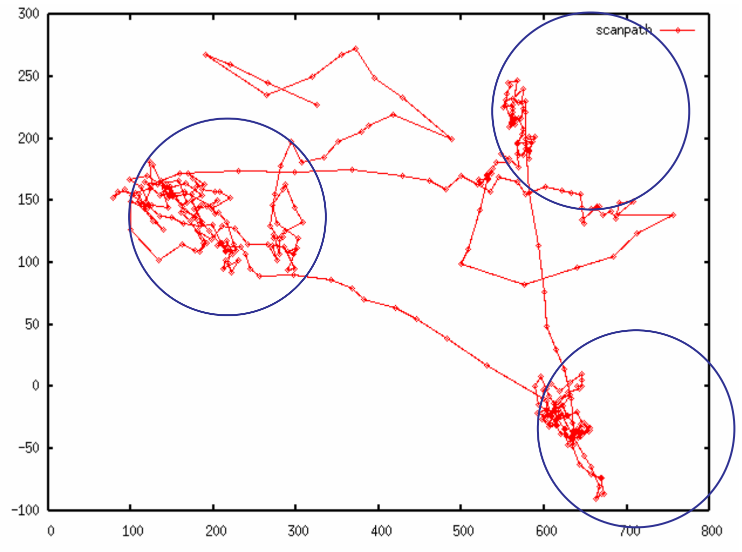
2.1 Computer Interfaces

Direct Usage of Head Movements: Hands-Free Mouse



How to Use Eye Movements for Computer Interfaces ?

- Eye movement [Glenstrup 95]
  - Convergence
  - Rolling
  - Saccades
  - Pursuit motion
  - Nystagmus
  - Drift and micro-saccades
  - Physiological nystagmus



- Need to refine raw data:
  - distinguish Fixations from Saccades

How to Use Eye Movements for Computer Interfaces ?

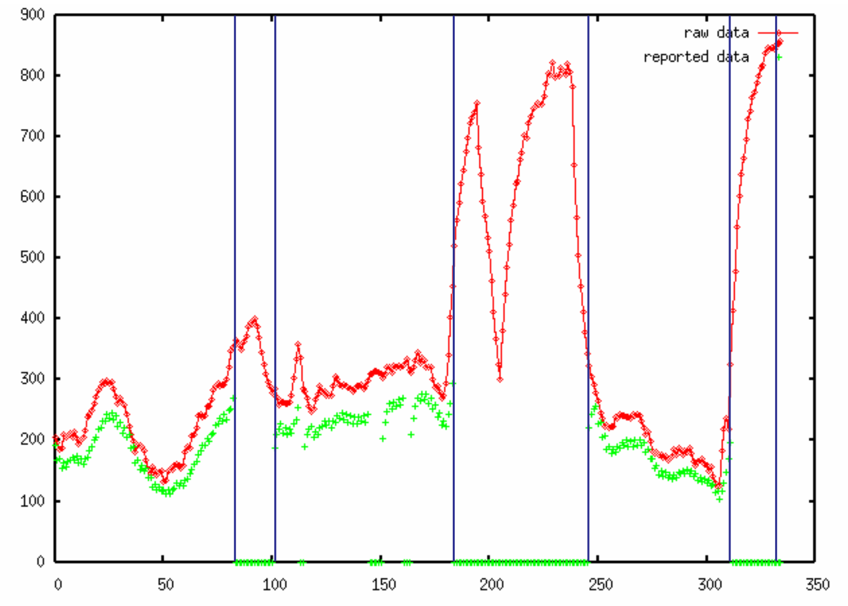
Saccade/Fixation detection

- Velocity-Threshold
  - Saccades >300 deg/sec.
  - Fixations <100 deg/sec.
  - Usual threshold 200 deg/sec.

- Dispersion-Threshold

$$D = \frac{\max(x) - \min(x)}{\max(y) - \min(y)}$$

  - Threshold set such that visual angle is between 0.5 ° and 1°.



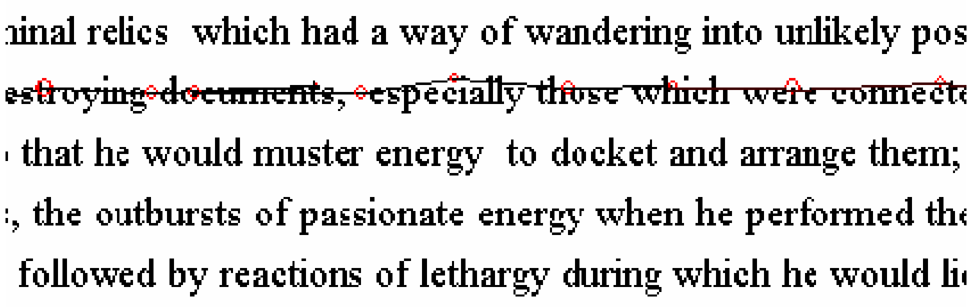
How to Use Eye Movements for Computer Interfaces ?

- Command based Interface
  - Obvious application: Selection of objects {Menu selection, Window scrolling, …) ⇒ Pointing.
  - Midas Touch problem: Eyes not a control device.
  - Use *dwell time* to trigger a selection.
- Non-Command Interfaces
  - The computer monitors user's actions instead of waiting for user's command.
  - Potential Applications: User Support

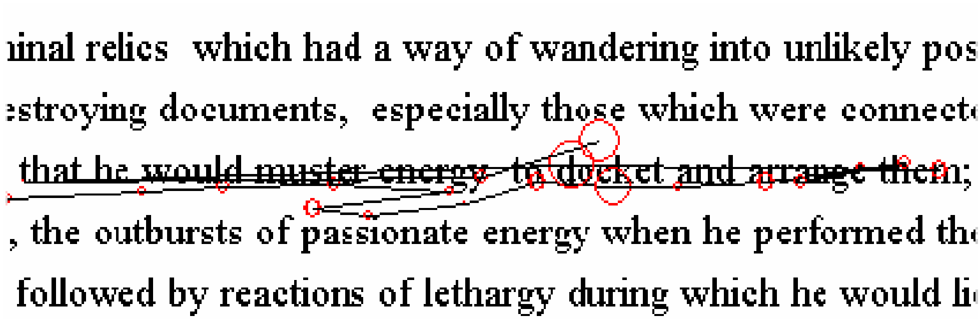
    ⇒ Detect difficulties and provide translation support of difficult words

Pro-Active Dictionary: How to detect User Difficulties?

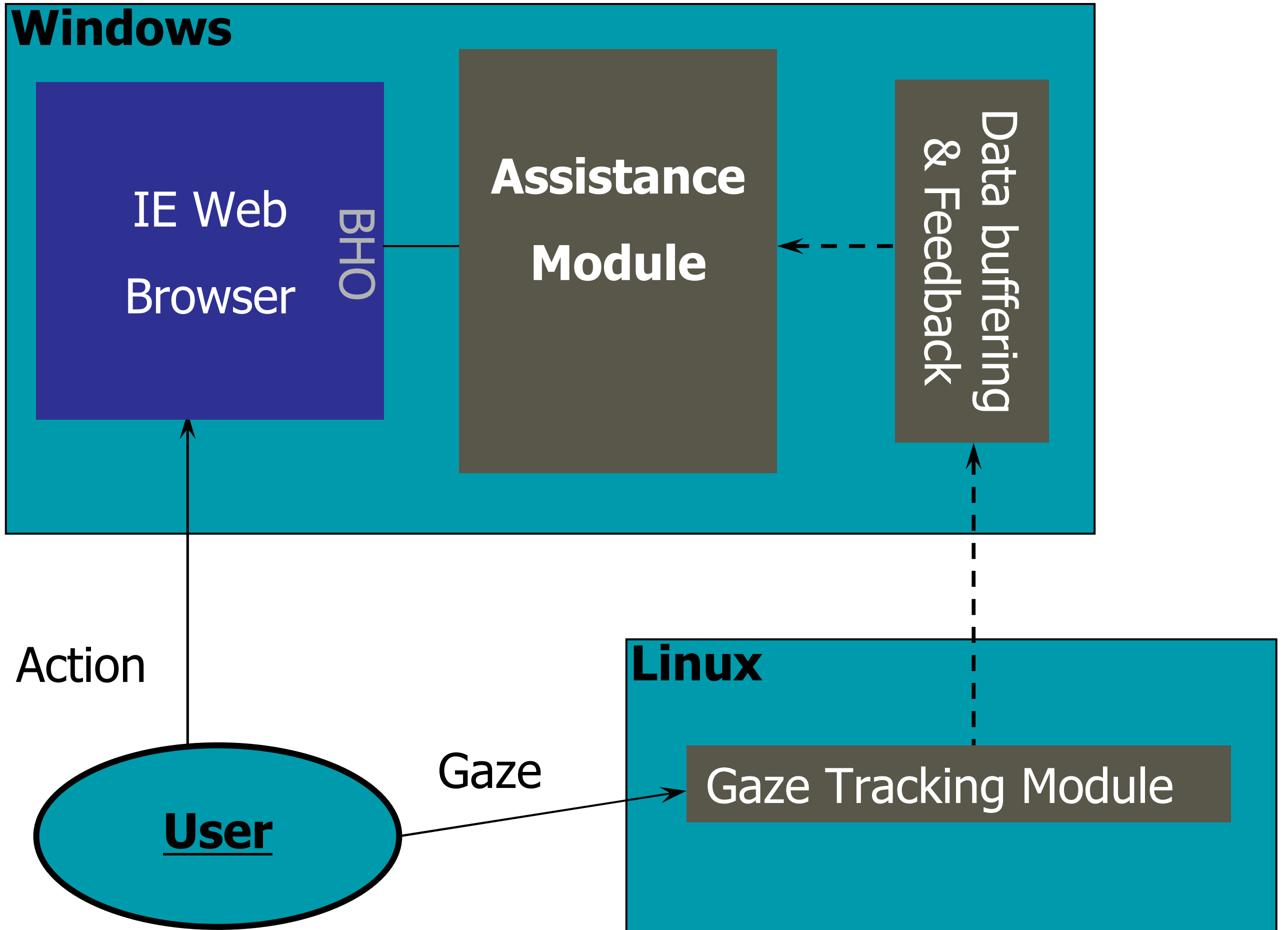
Gaze Pattern in Normal Reading



Gaze Pattern when Difficulties Encountered



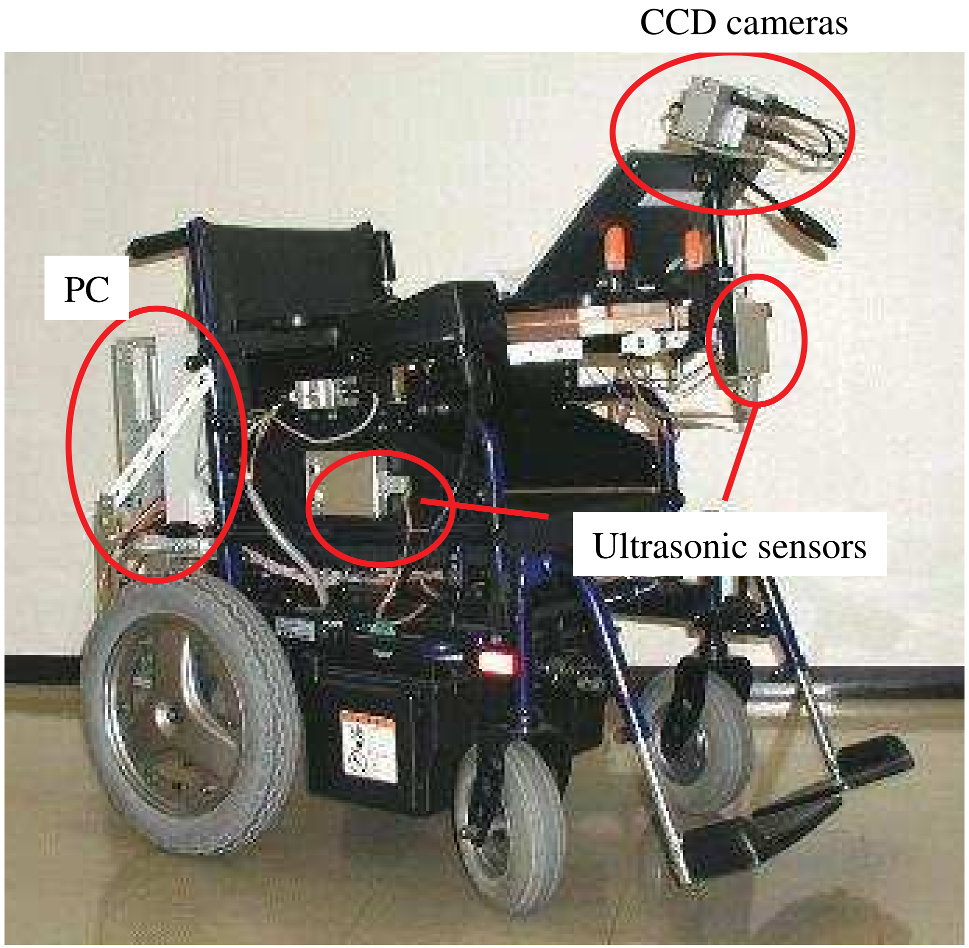
Pro-Active Dictionary: Implementation

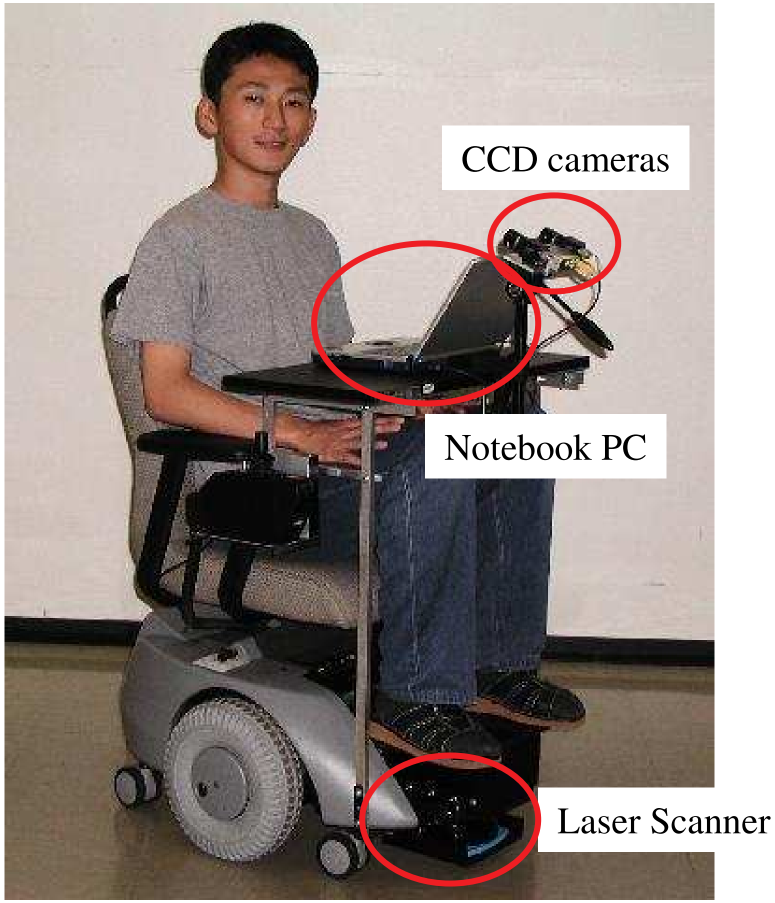


Pro-Active Dictionary: Demonstration

2.1 Robot Interfaces

Intelligent Wheelchair





Intelligent Wheelchair

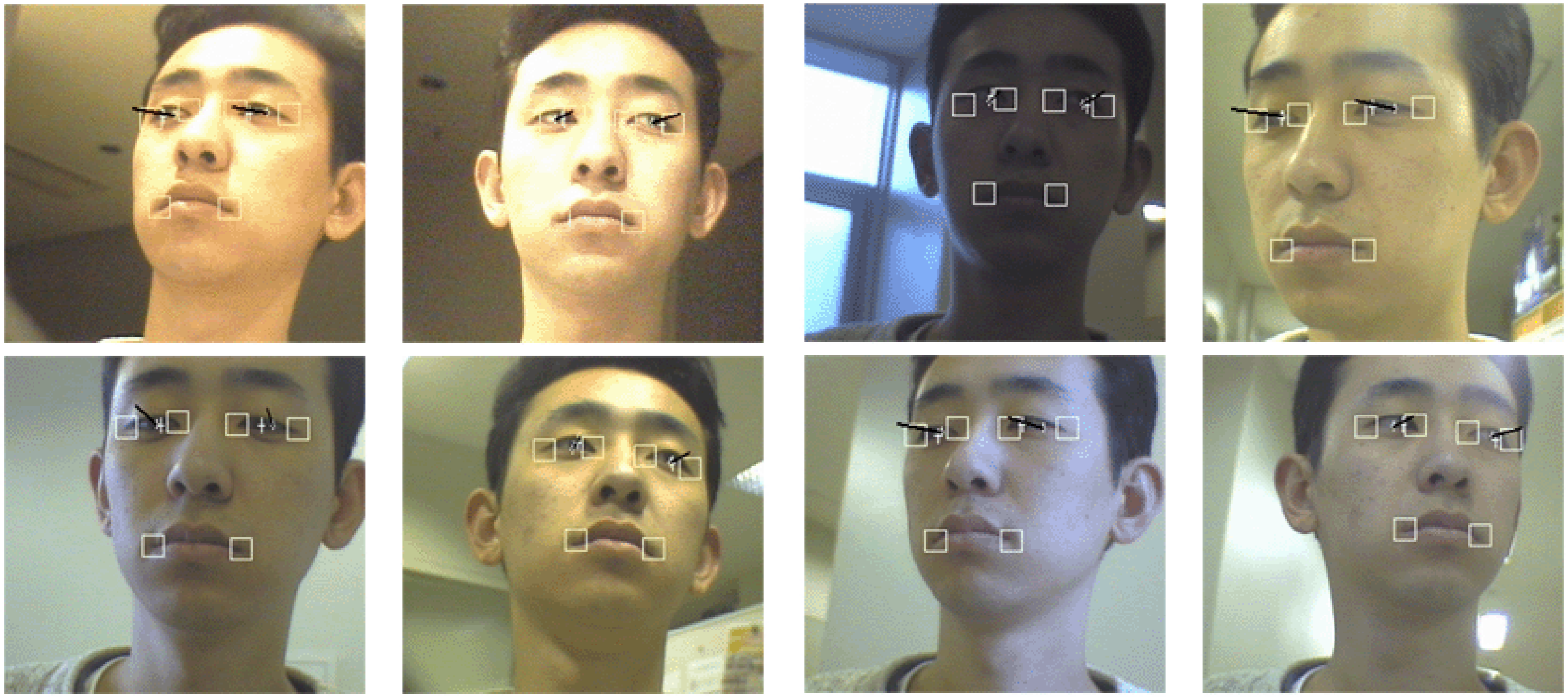
How is facial information used ?

- Gesture
  - Nodding -> To start
  - Shaking ->To stop
- Face Direction
  - To determine the direction to move
- Gaze Direction
  - To determine if the user is concentrated

Intelligent Wheelchair

Intelligent Wheelchair

Various lighting conditions

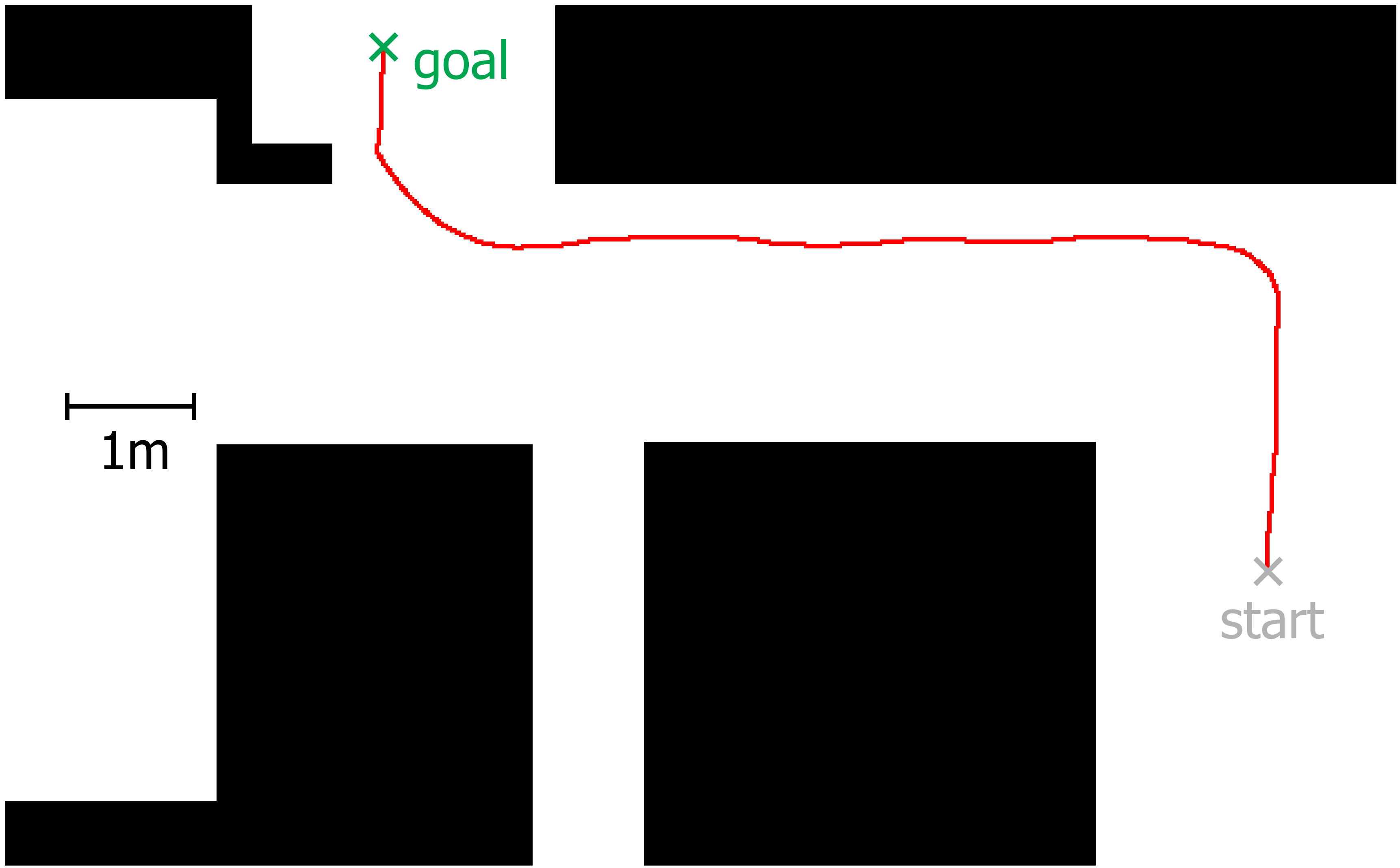


Intelligent Wheelchair

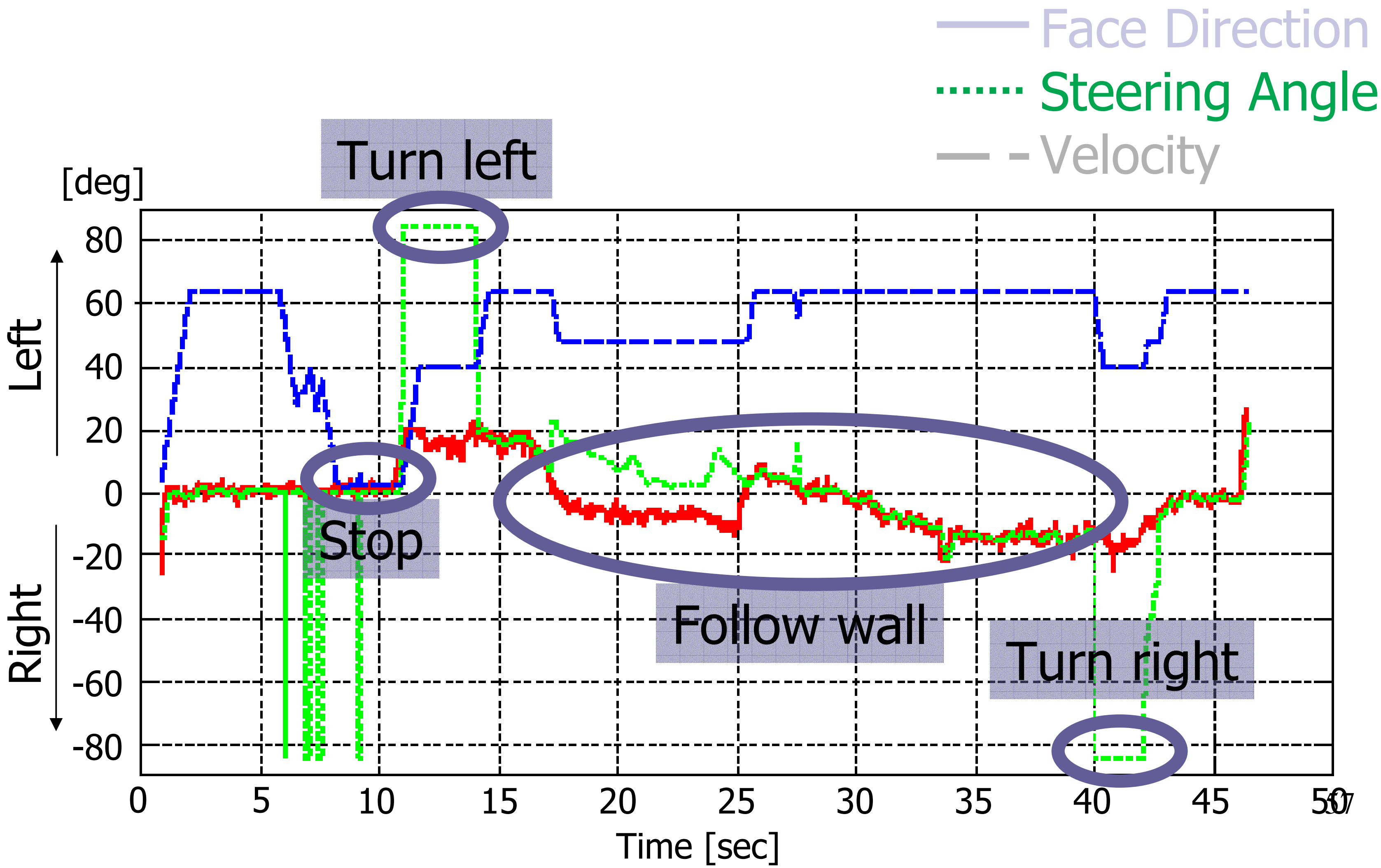
Intelligent Wheelchair

Sensor-based collision avoidance and wall following

Result of Experiment (Trajectory)

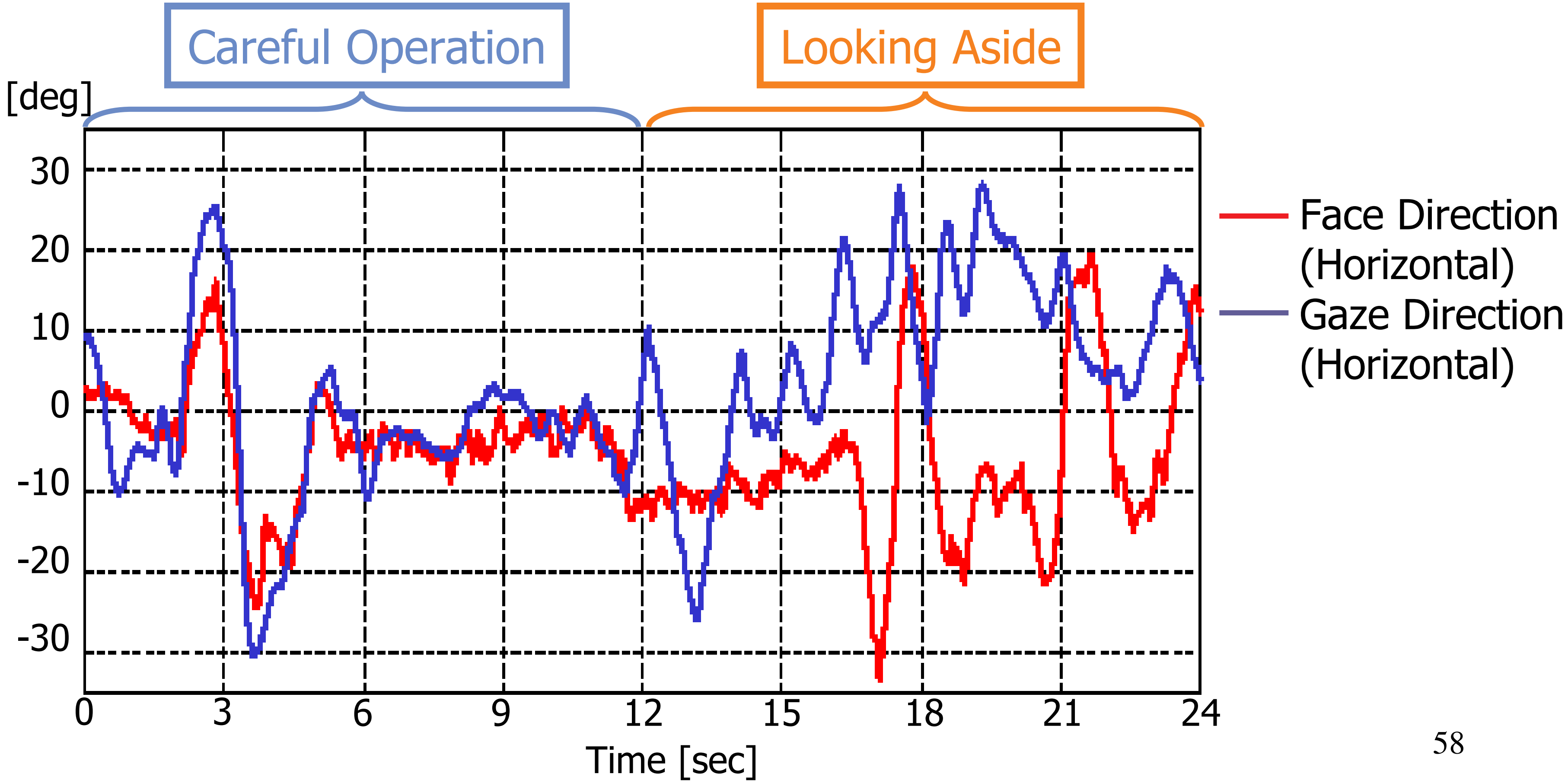


Result (Input and Output Values)



Intelligent Wheelchair

How to detect concentration of the user?

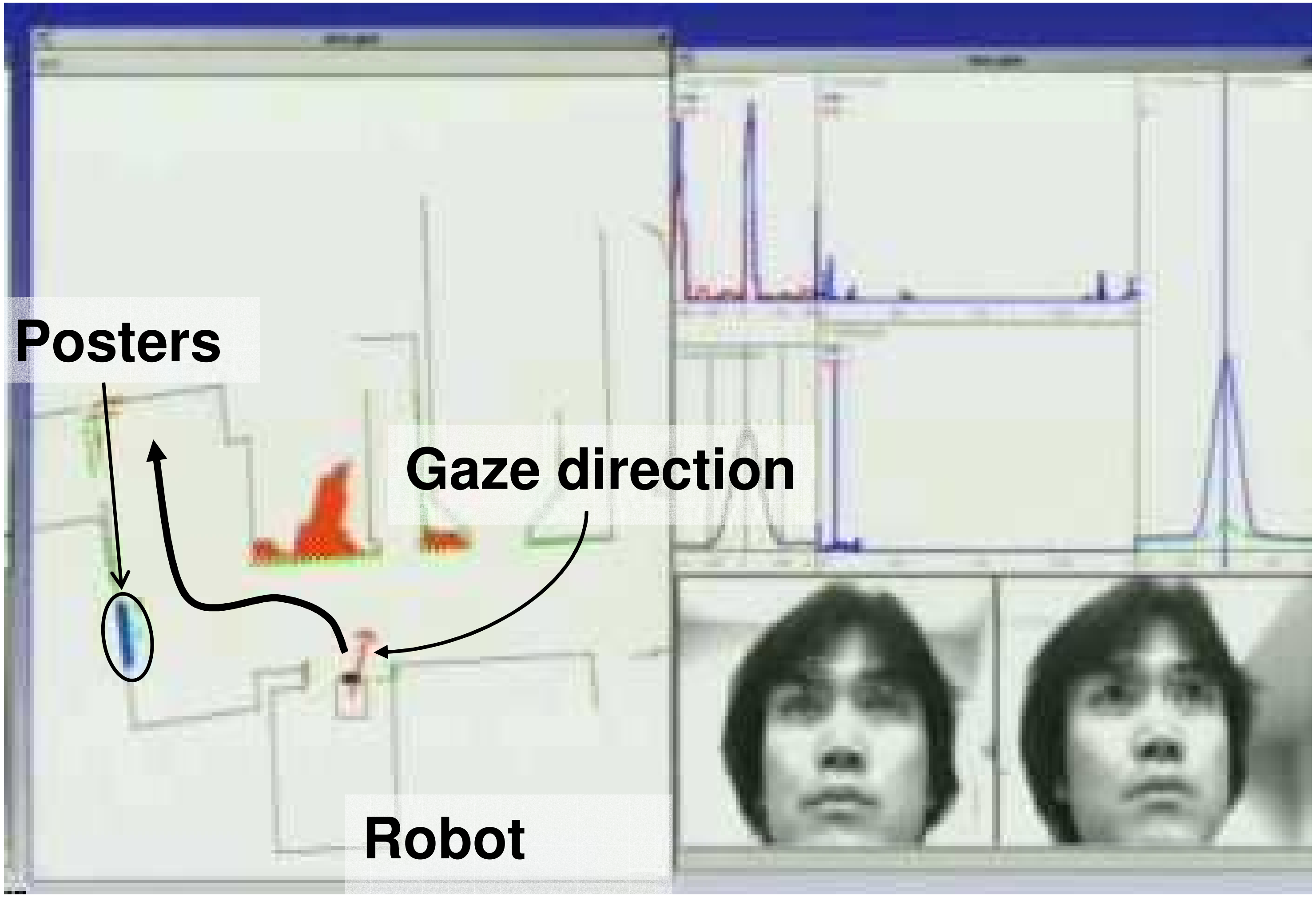


Intelligent Wheelchair

Estimation of User's Attention

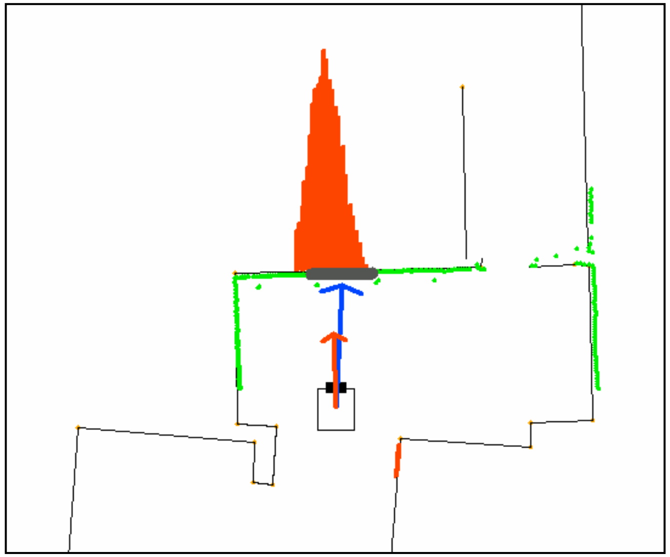
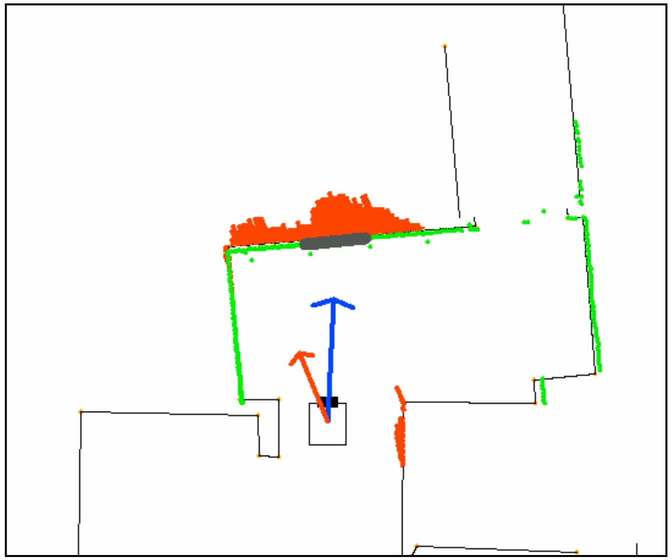
Intelligent Wheelchair

Estimation of User's Attention



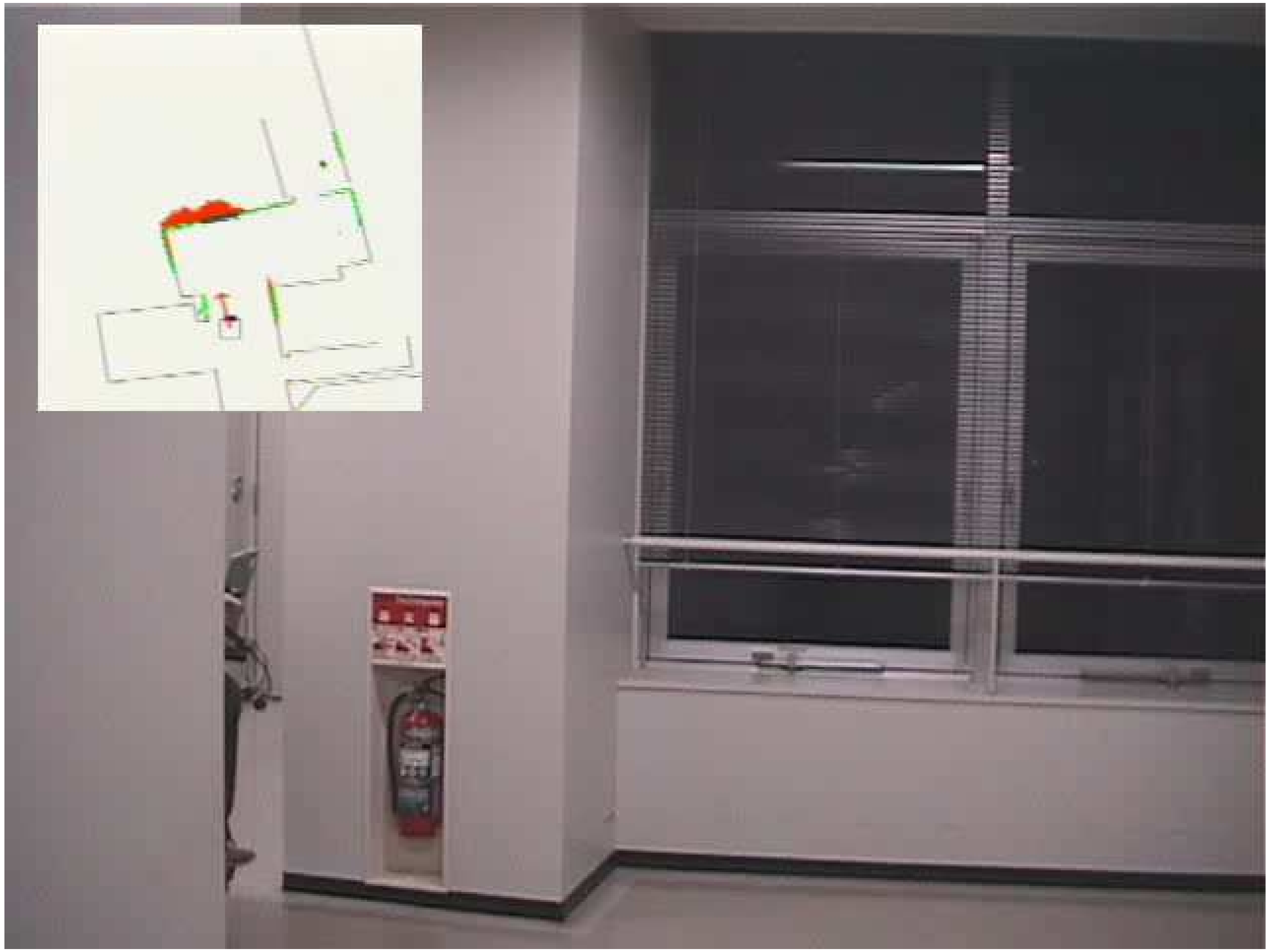
Intelligent Wheelchair

Estimation of User's Attention

Paying attention to the poster	Not paying attention to the poster
	
u Concentrated on the position of the poster.	u Distributed on various positions.

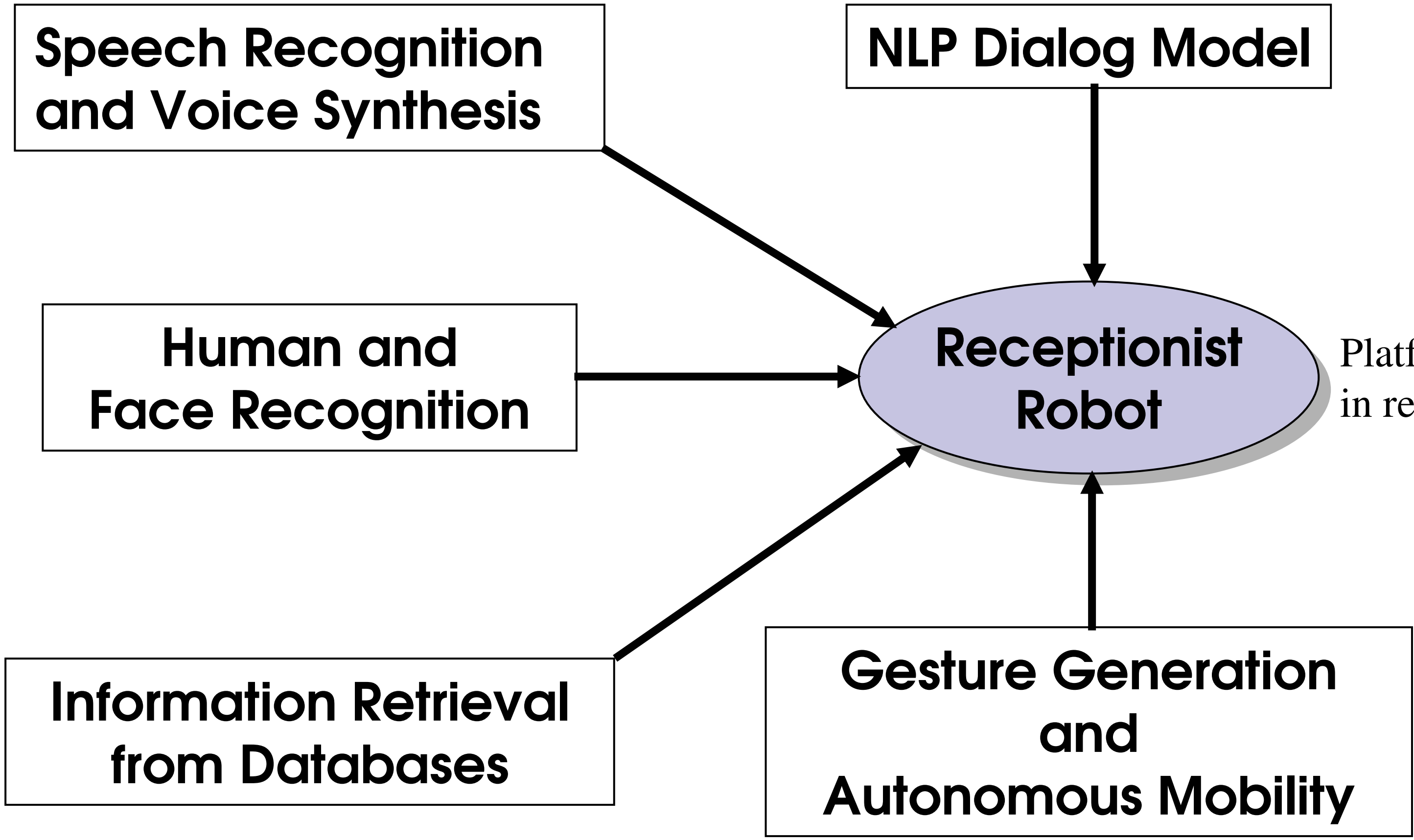
Intelligent Wheelchair

Estimation of User's Attention



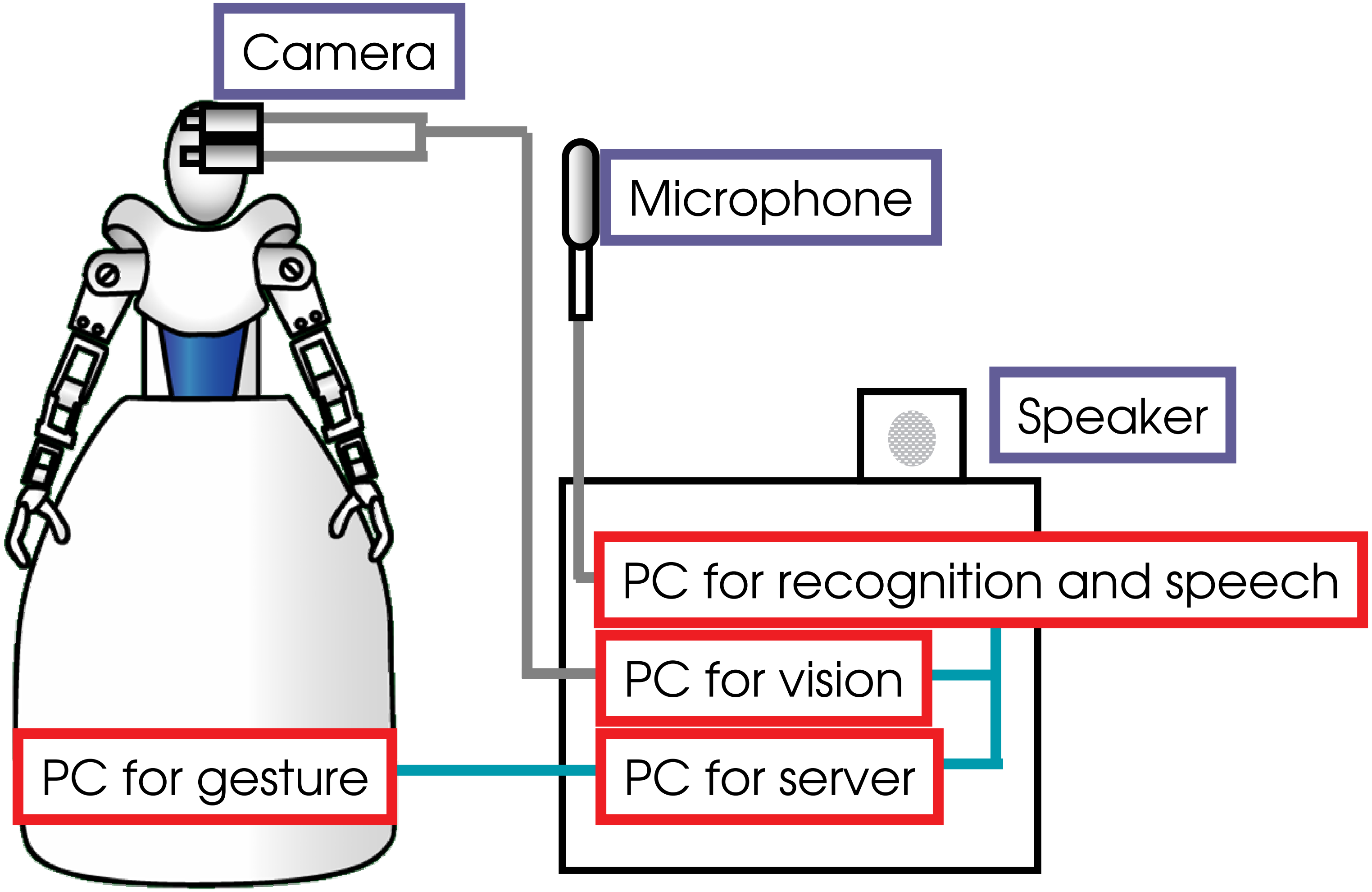
Receptionist Robot ASKA

Receptionist Robot ASKA

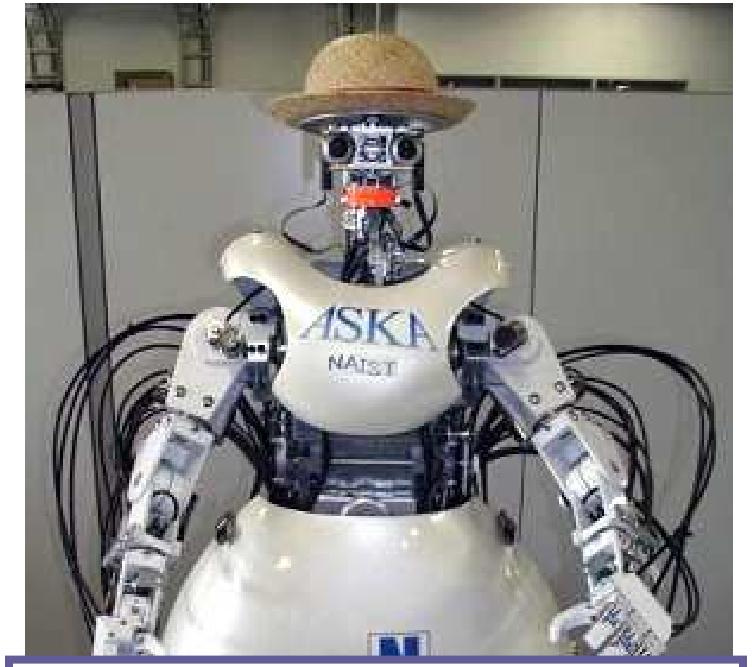


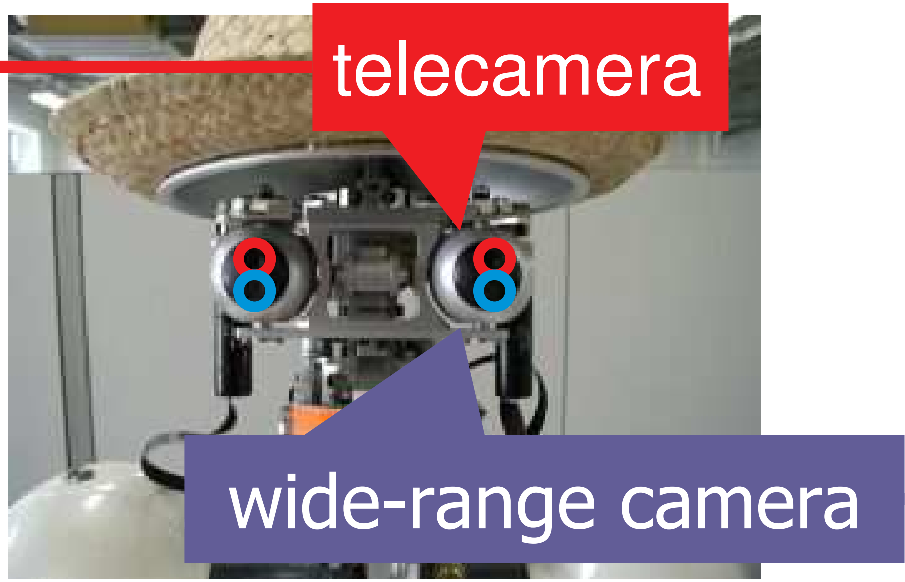
Platform for experiment
in real world

ASKA: System Overview



Hardware Configuration





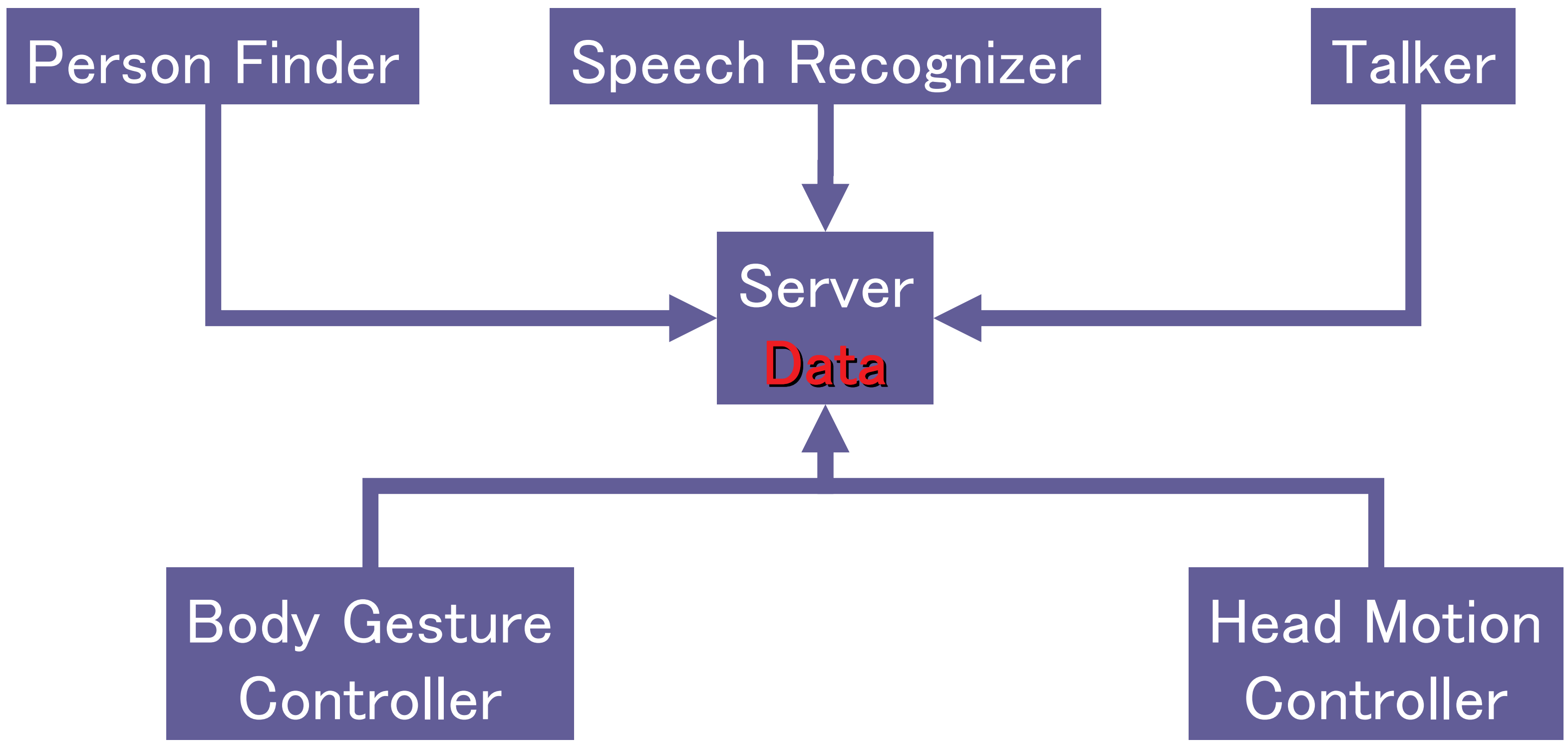
Human detection and tracking

Measurement of facial information

Base:
tmsuk04 (tmsuk Co., LTD.)

Degree of freedom:
- Chest 1 (DOF)
- Arms 14 (DOF)
- Hands 6 (DOF)

Software Configuration



Receptionist Robot ASKA

Problem to Solve with Vision

Problem

Wrong responses to :

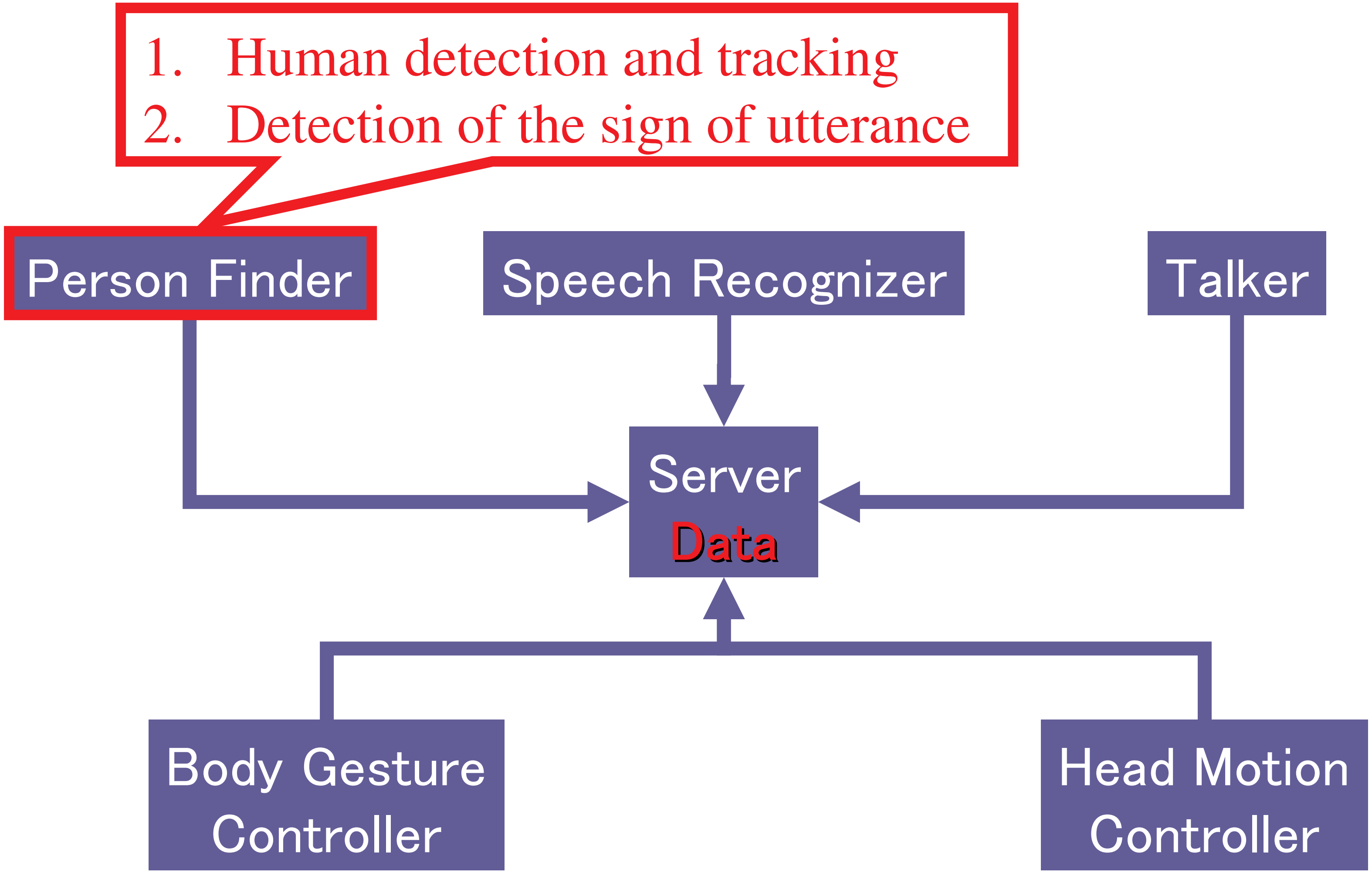
- Ø Background noises
- Ø Utterances which are not spoken to ASKA

Purpose of This Research :

- To recognize the utterance period
- To detect whether user speaks to ASKA or not

For natural human-robot interaction.

Software Configuration



Pilot Study

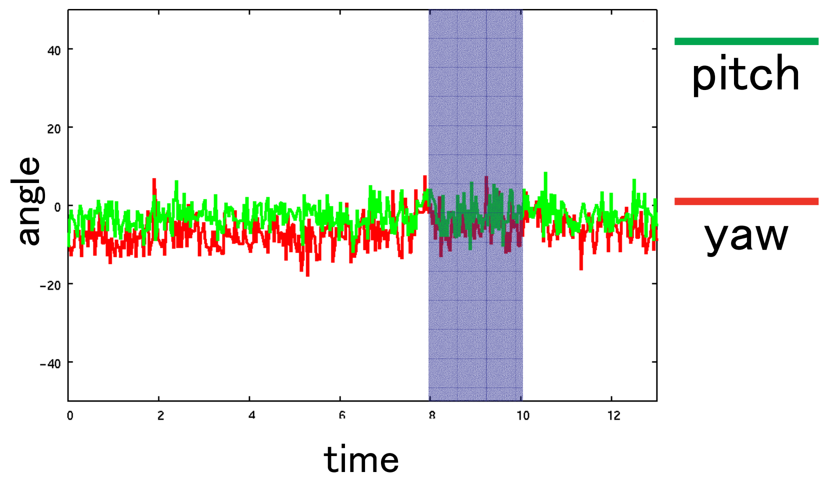
Dialog Experiment

- Measured information
  - Head orientation
  - Gaze
  - Lip motion
  - Blink
- Subject
  - 10
- Speech sentence
  - Fixed sentence : 5
  - Free sentence : 5

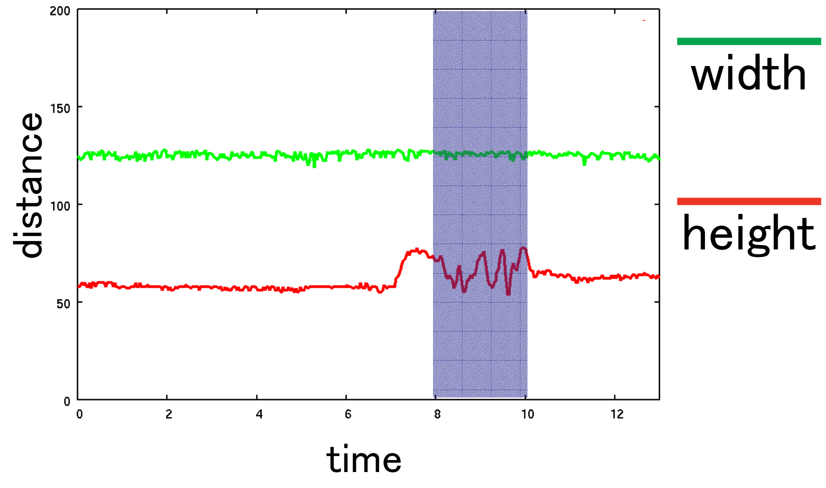
Information at Utterance

Subject A

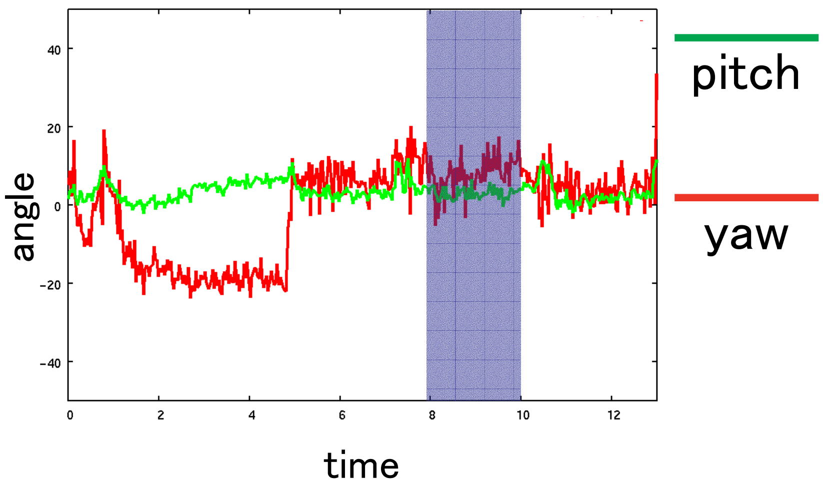
Head orientation



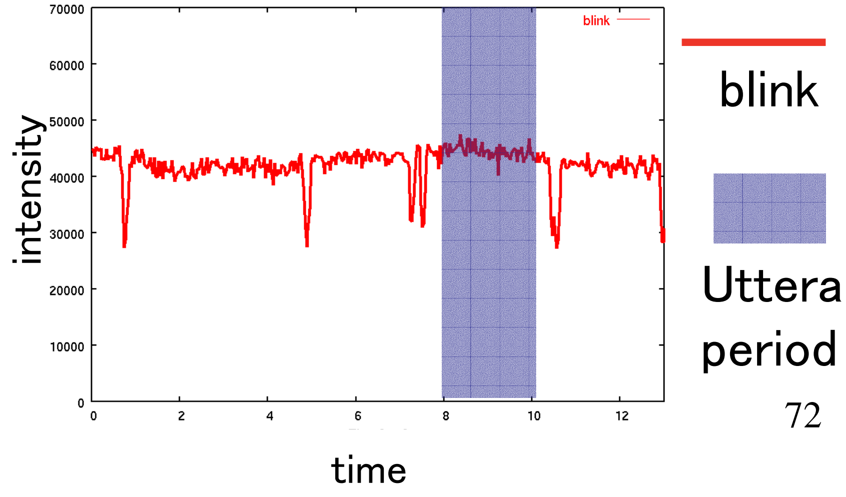
Lip distance



gaze

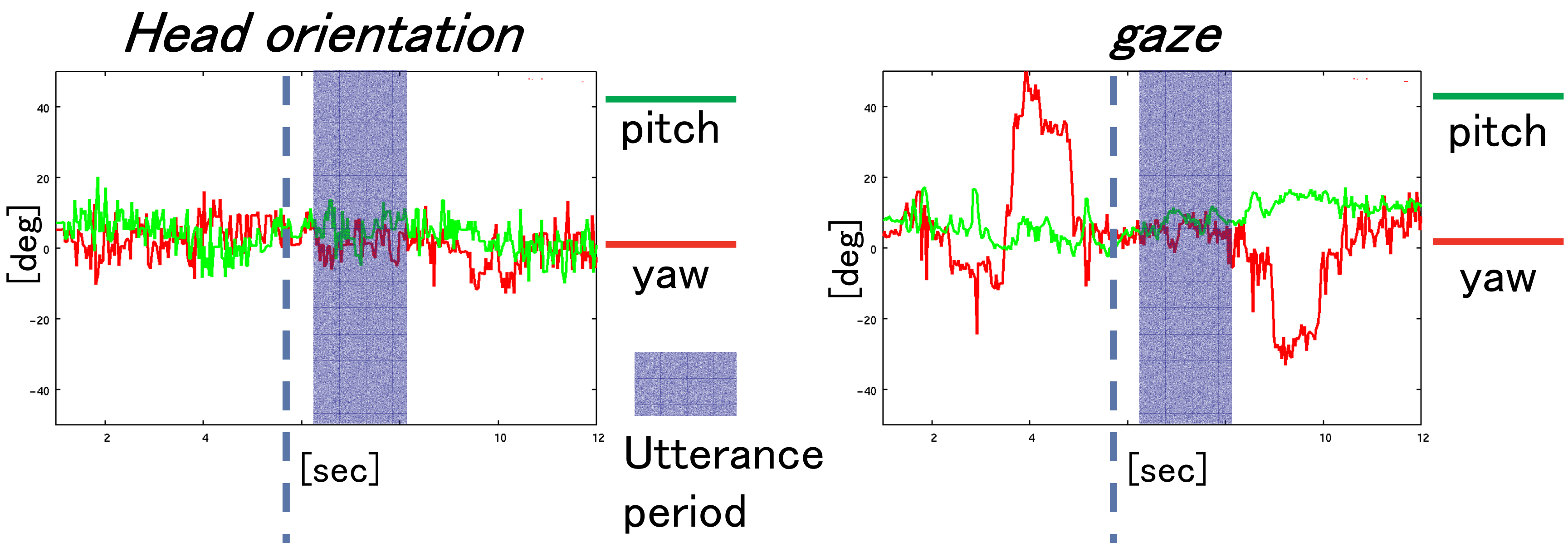


blink



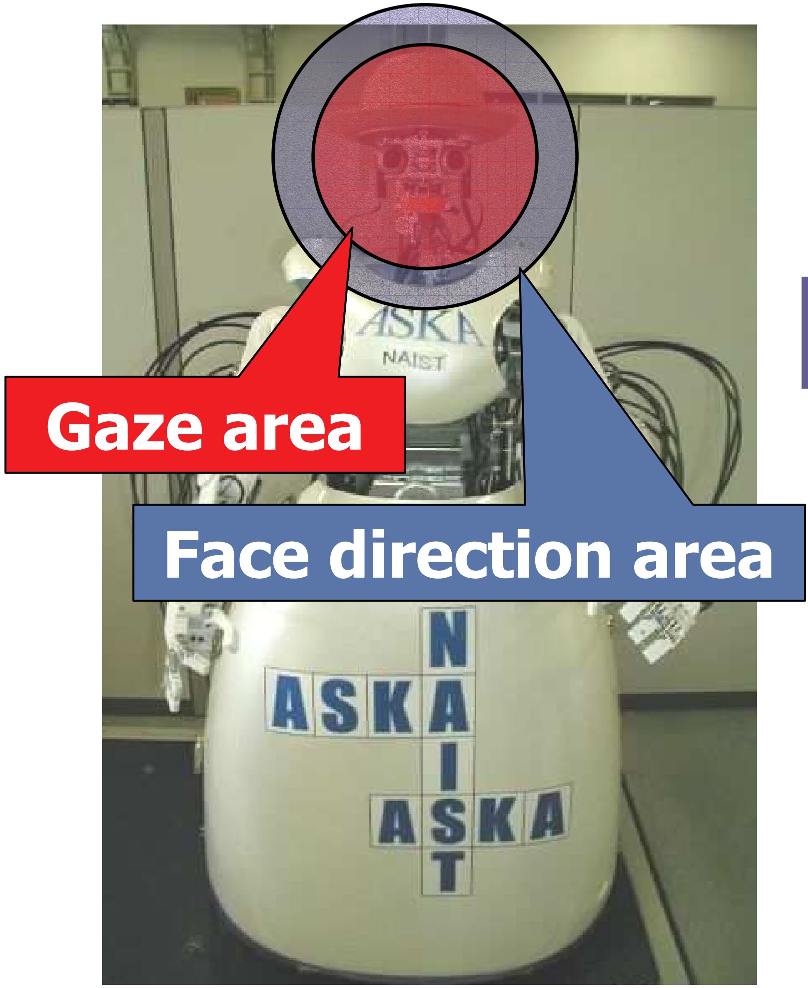
Sign of Utterance : Start

Subject B



The Face and gaze direct to object before the utterance

Sign of Utterance : Start



Face and gaze vectors are within the threshold area.

↓

A user have an intention of utterance

<u>Allowing area</u>

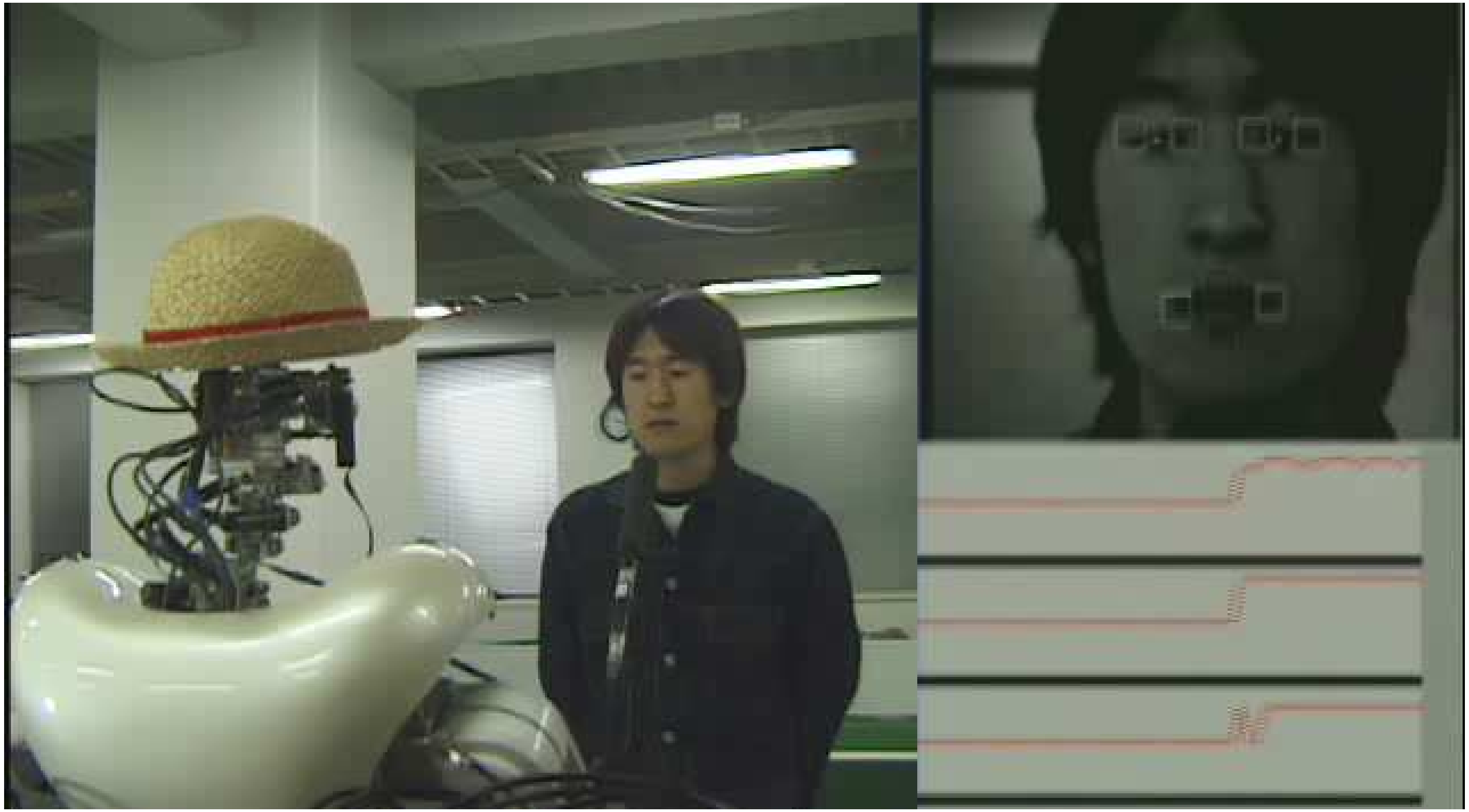
From the center of ASKA's face :

- Gaze vector area 300 [mm]
- Face vector area 400 [mm]

↓

Detection of Start of Utterance

Experiment : Detection of Utterance Sign



Demonstration :
Interaction Based on Utterance Sign

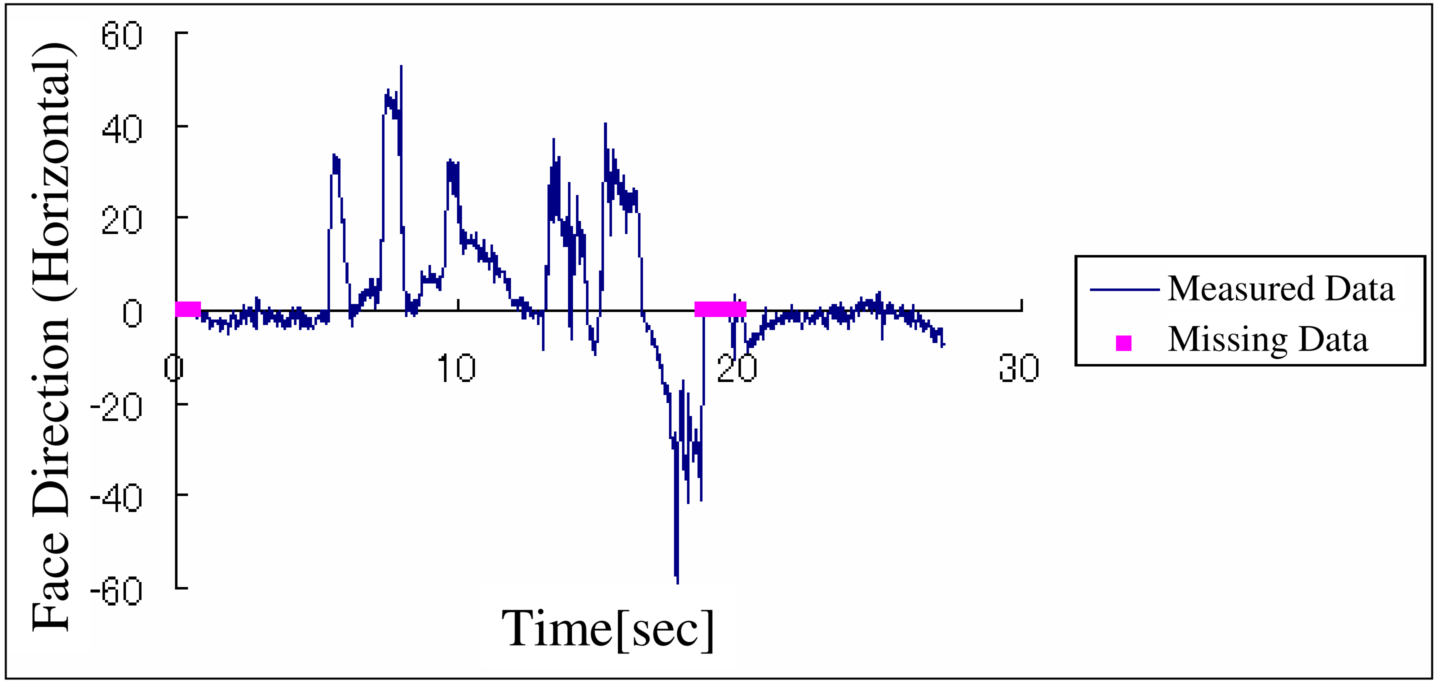
3.Application to Human Modeling

Measurement of Infants

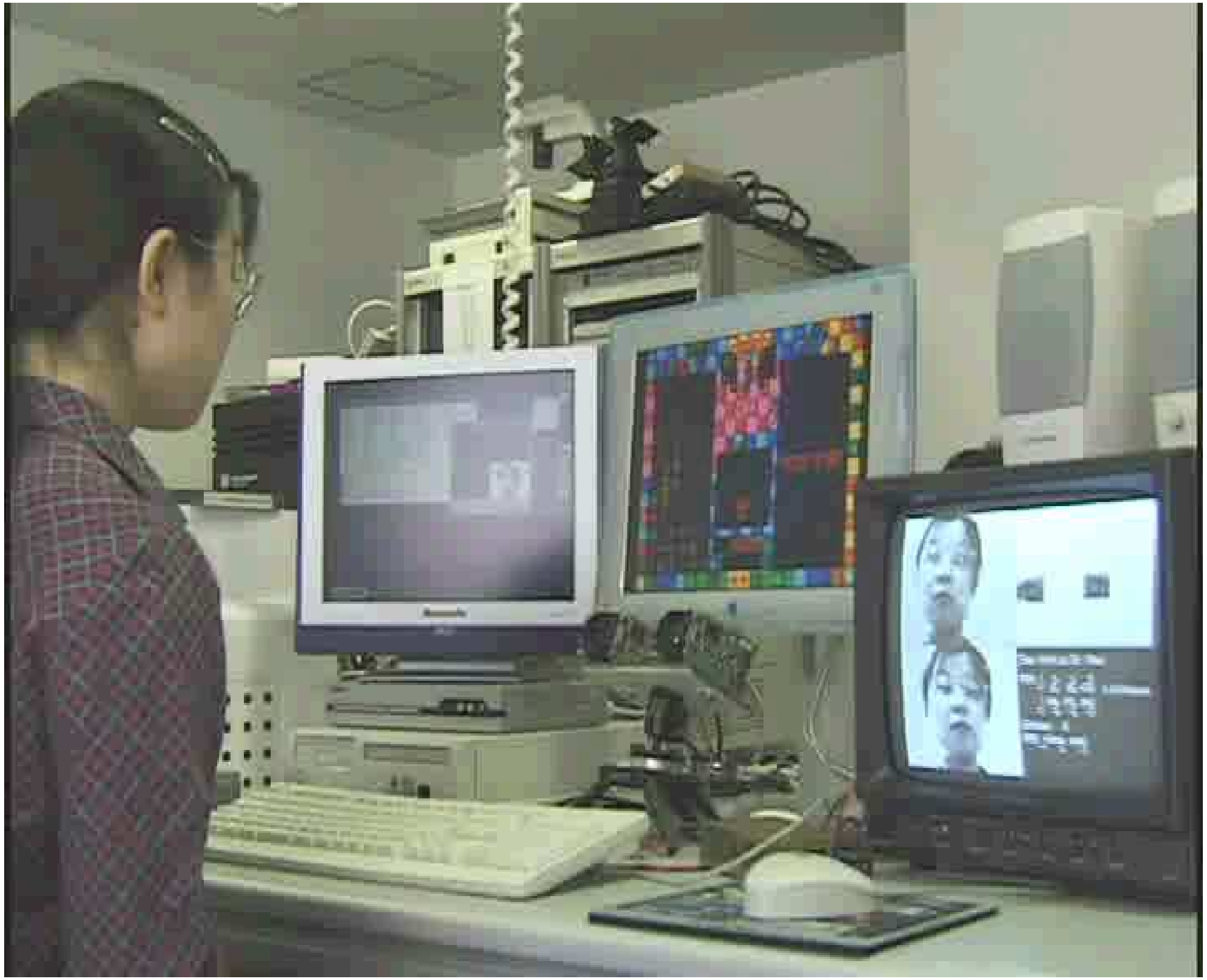
Measurement of Infants

Measurement of Infants

Measured Results

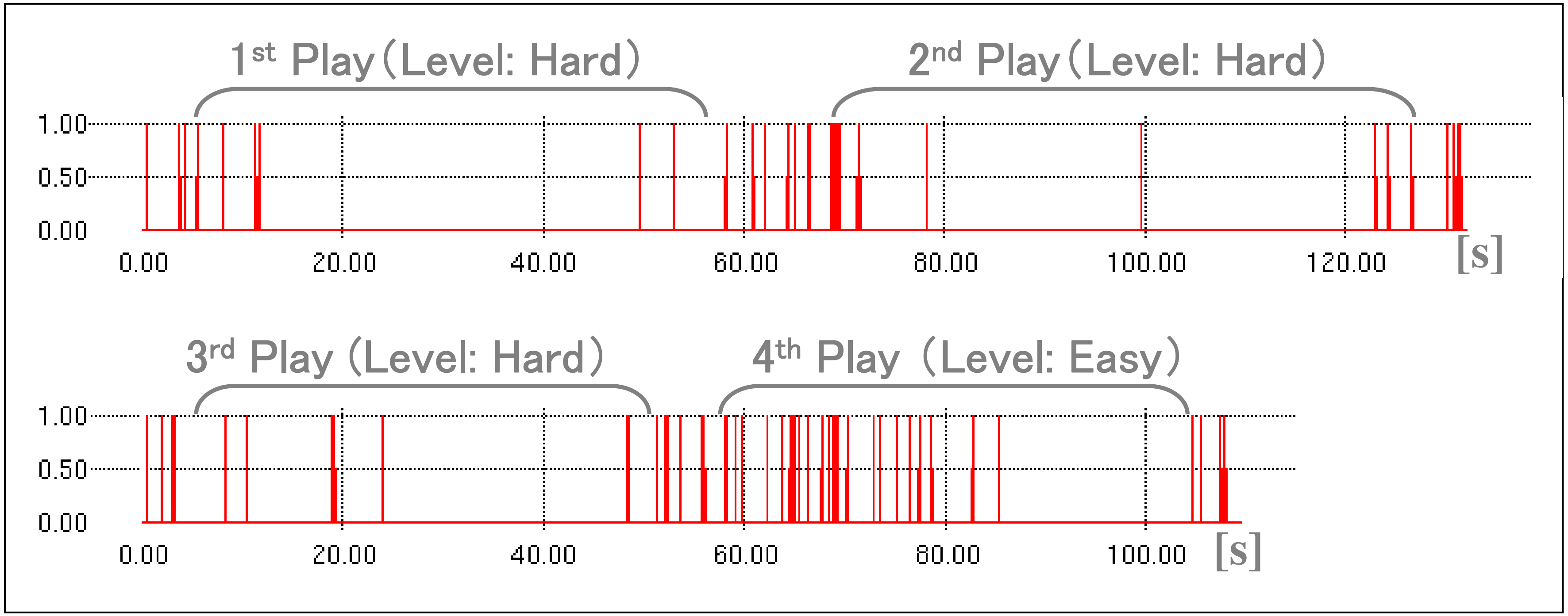


Measurement of TV Game Players



Measurement of TV Game Players

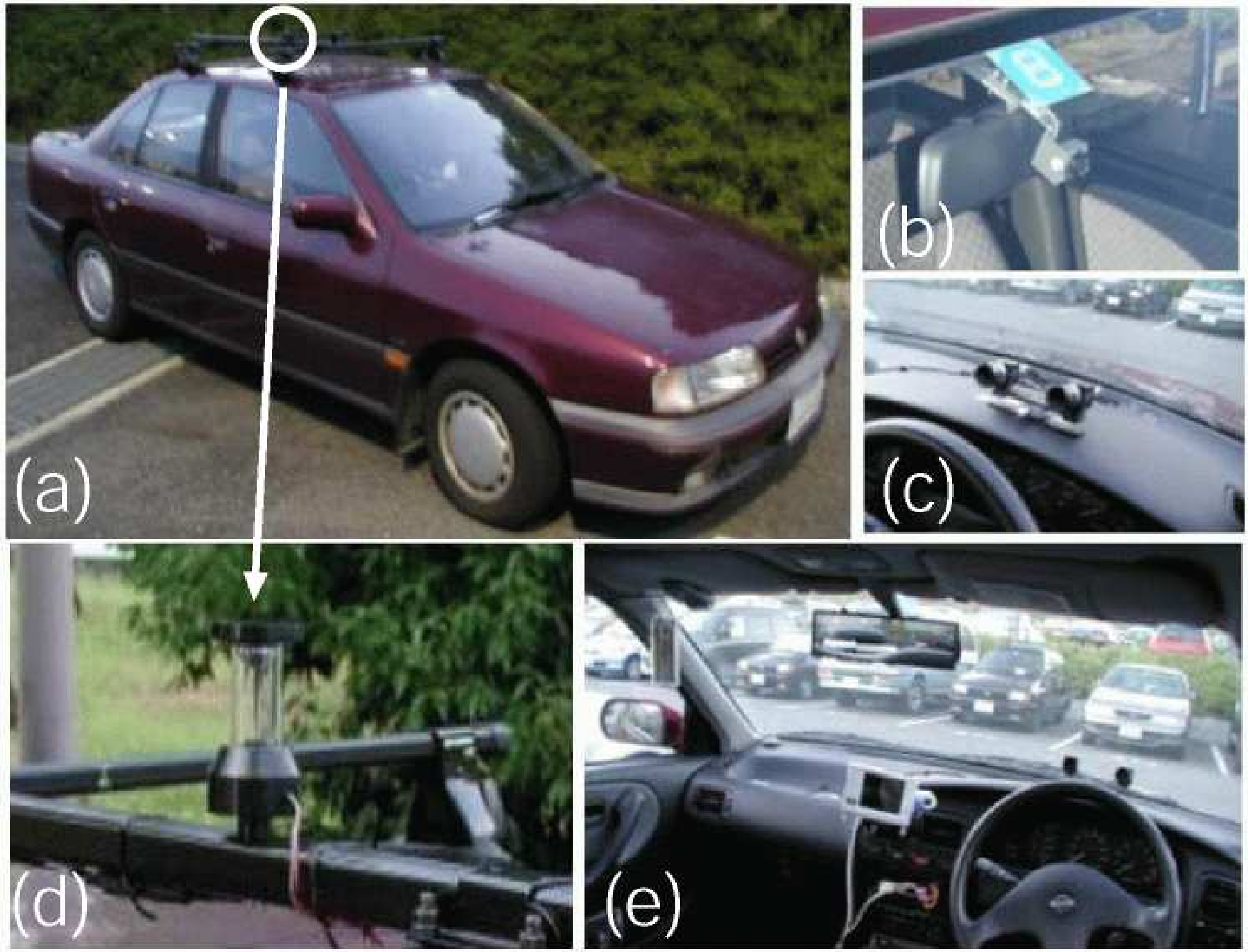
Frequency of Blinking



This result coincides with Psychological Report

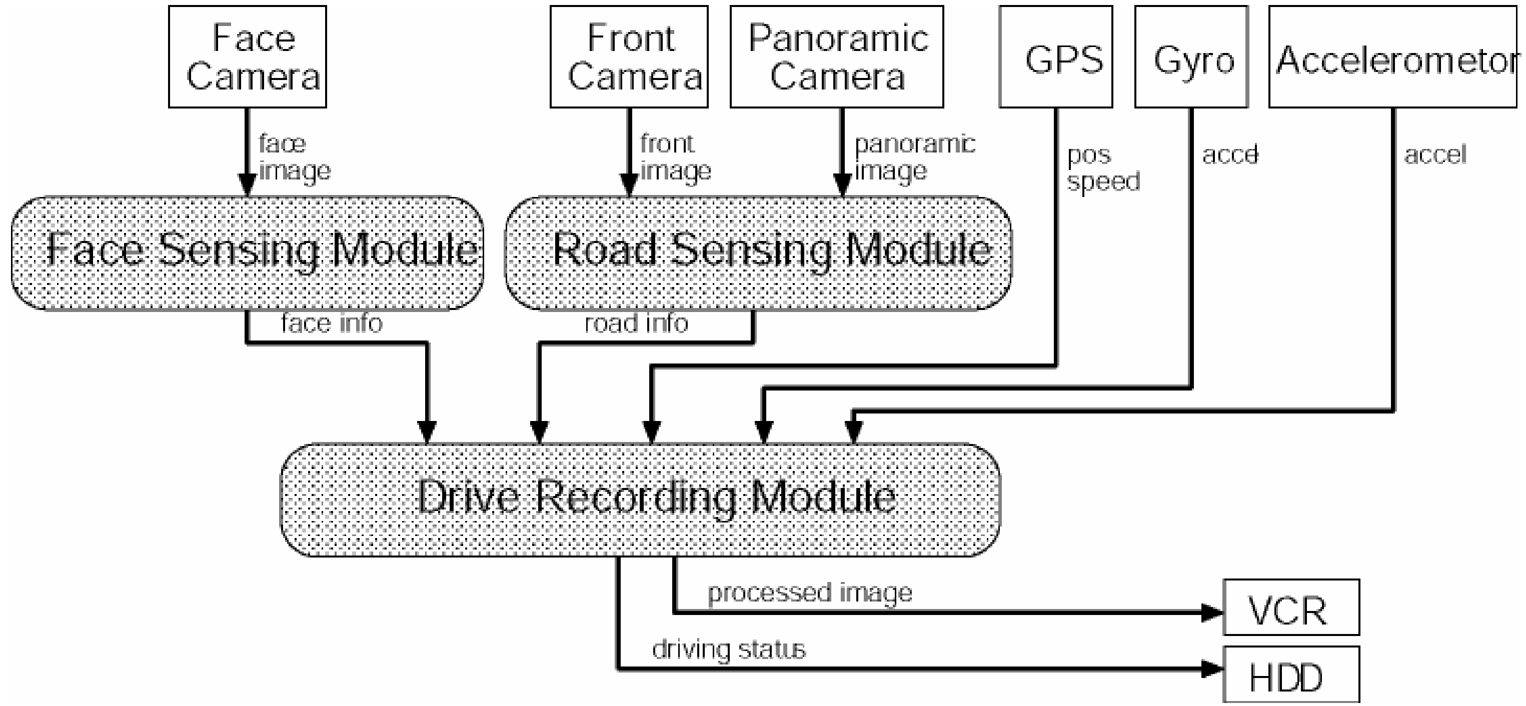
Measurement of Drivers

System overview



Measurement of Drivers

Software Configuration



Measurement of Drivers

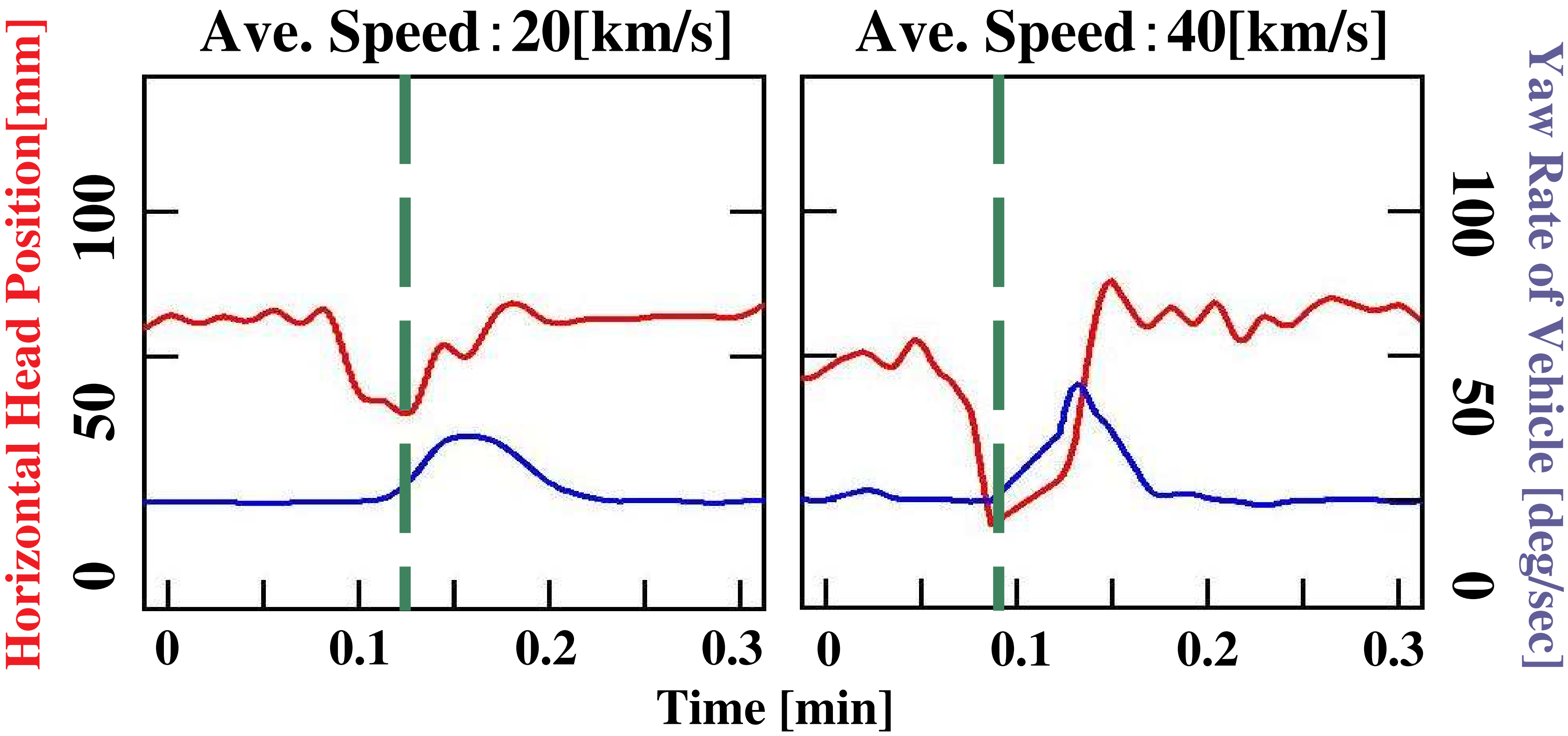
Measurement of Drivers

Measurement of Drivers

Experiment at night

Measurement of Drivers

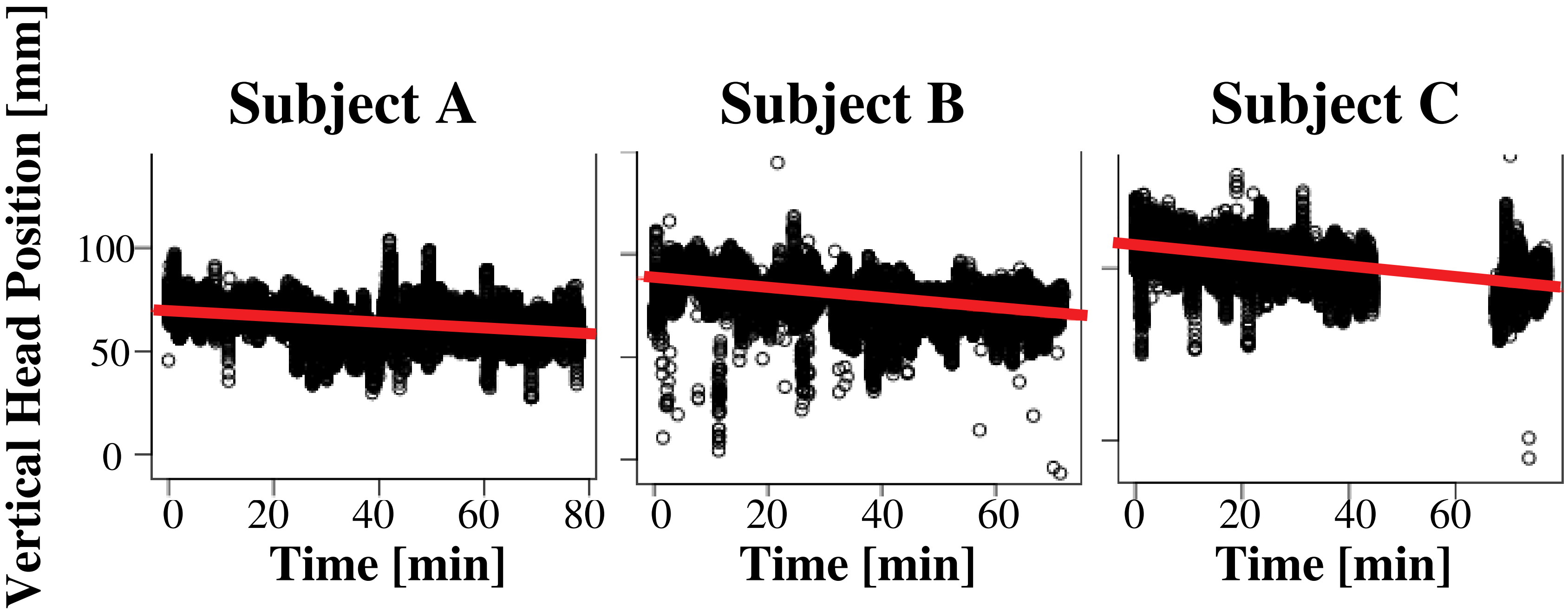
Horizontal head movements at curves



Not passive head movements due to centrifugal force,
but active head movements to cope with centrifugal force.

Measurement of Drivers

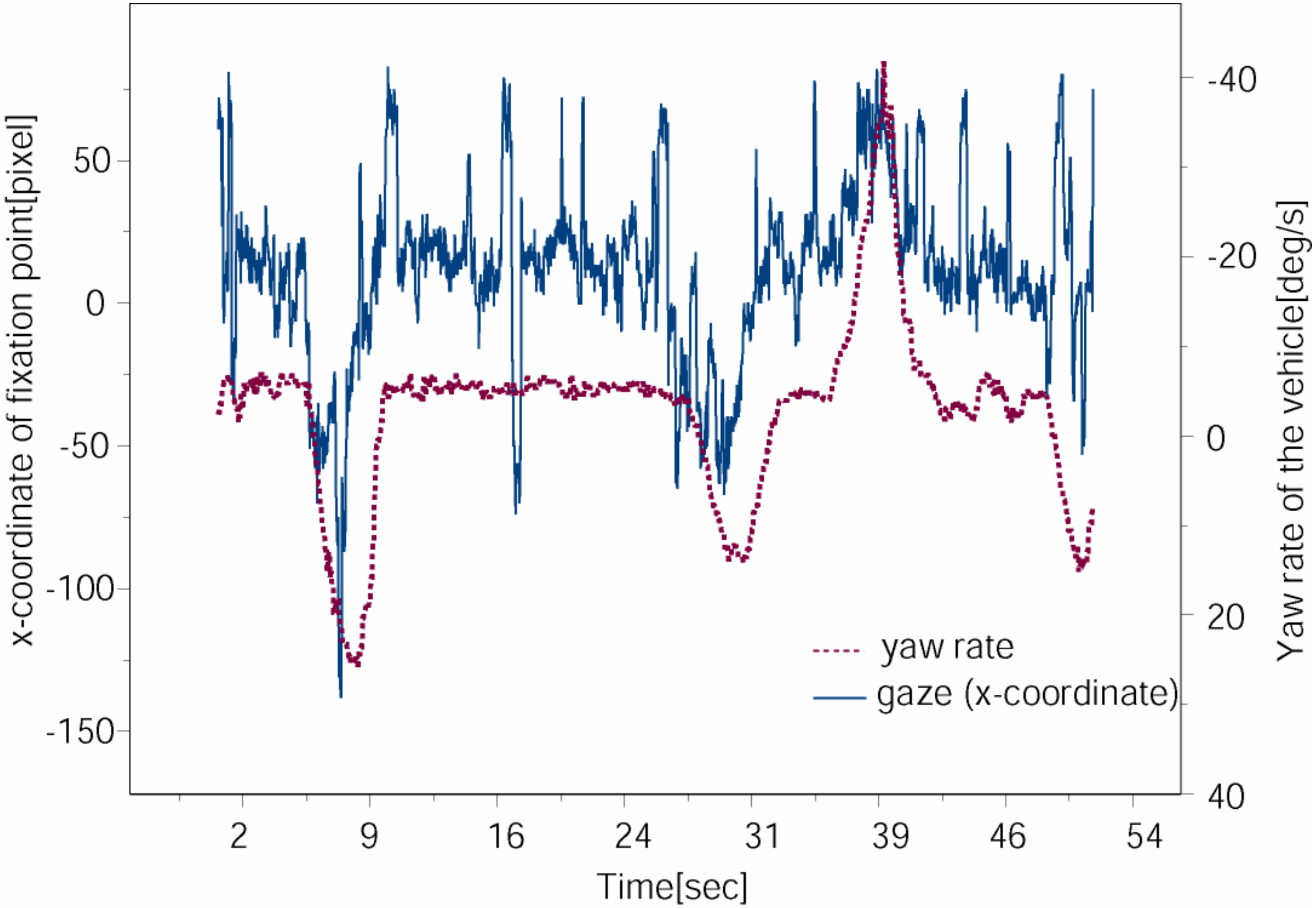
Vertical head position in long driving



- •Body posture changed after long driving ?
- •Body lowered due to the softness of the seat?

Measurement of Drivers

Measured fixation point and yaw rate of vehicle



Measurement of Drivers

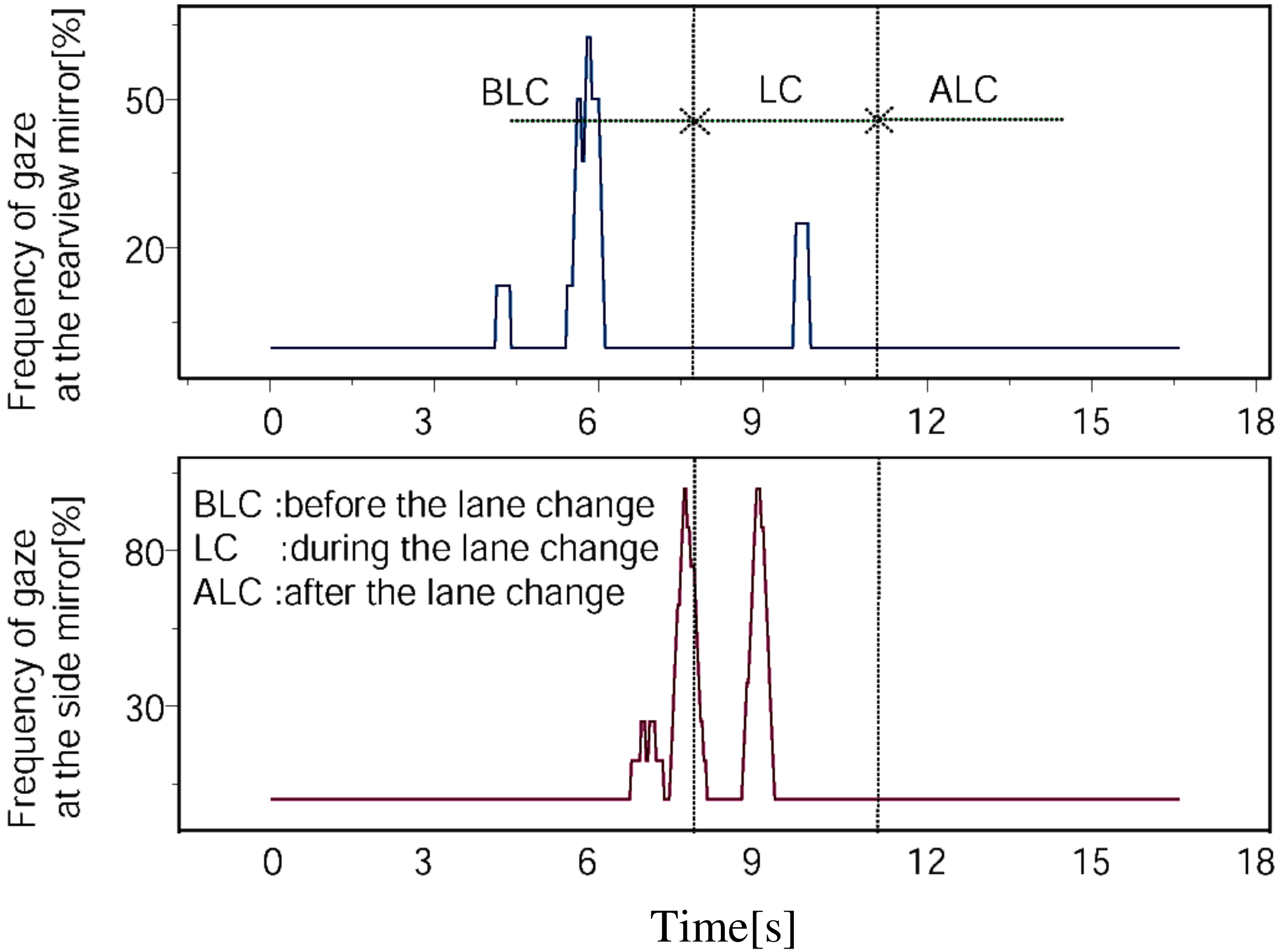
Attention Recognition

Measurement of Drivers

Attention Recognition

Measurement of Drivers

Where are you looking when lane changing?



Measurement of Patients in PET

To compensate head motion during measurement

Summary

Face Measurement System

Accuracy

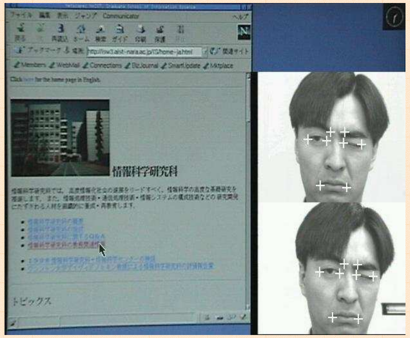
Head pos : 2mm
dir : 2deg
Gaze dir : 5deg

Processing Speed

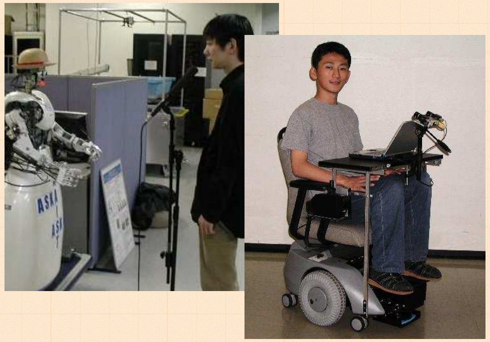
30Hz～80Hz
(depending on camera & CPU)

Human Interfaces

Computer Interface

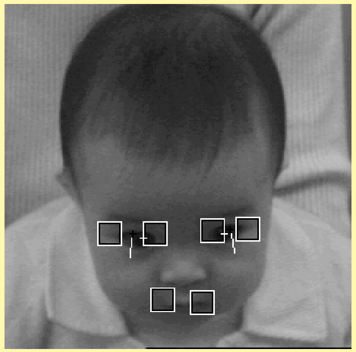


Robot Interaction



Human Modeling

Cognitive Science



Psychology / Ergonomics

Fin