Real Time and Non-intrusive Driver Fatigue Monitoring

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Introduction

Motivation

- Research reports that the leading cause for traffic accidents is due to driver with a diminished vigilance level.
  - (1) Drowsy driving accounts for 1,500 deaths and 100,000 crashes a year.
  - (2) 57% fatal truck accidents are due to driver fatigue.
  - (3) 70% of American drivers report driving fatigued.
- Building a system that actively monitors a driver's level of vigilance and alerts the driver of any insecure driving conditions for accident prevention.

Existing Works

Many efforts have been reported. They can be classified as:

(1) Vehicle-based performance technologies

Monitoring the transportation hardware systems: driver's steering wheel movements, lane change, acceleration, braking and gear changing, etc.

(2) In vehicle and online driver status monitoring technologies

(A) **Intrusive methods**

- Physiological measurements such as EEG, EOG, EKG
-- Head-mounted devices (eye movement, head movement)
-- Contact lens (eye movement), wristwatch-style for pulse measurement
-- Driver response monitoring

(B) **Non-intrusive image-based methods**

remote video cameras: monitoring eyelid movement, eye gaze, head movement and facial expressions.

Existing Works (Cont'd)

Problems with the existing online monitoring :

- use only only one parameter. Fatigue parameters are uncertain and ambiguous.

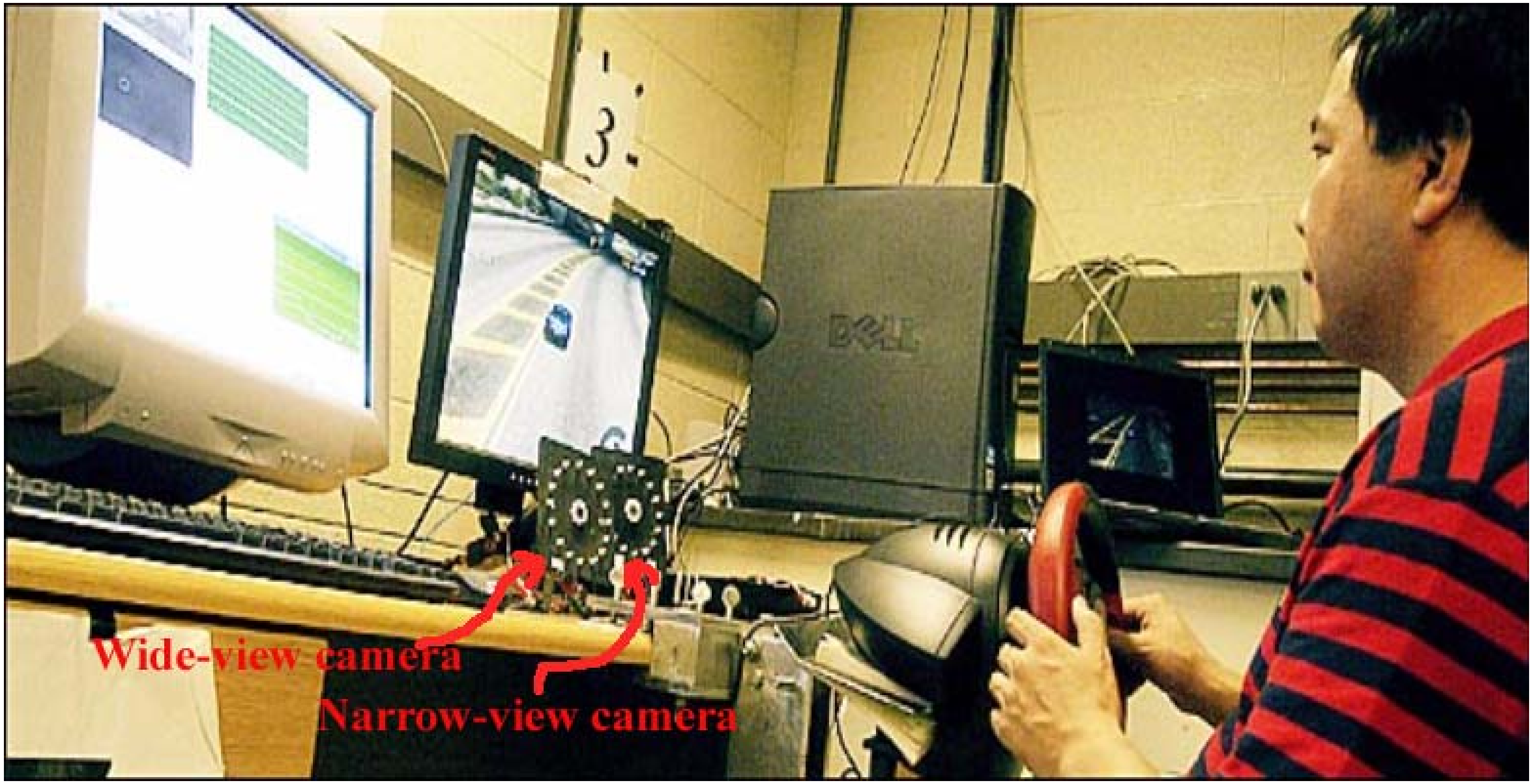
- does not systemically model fatigue and the factors leading to and reflecting fatigue

System Setup

Our system is a two-camera system:

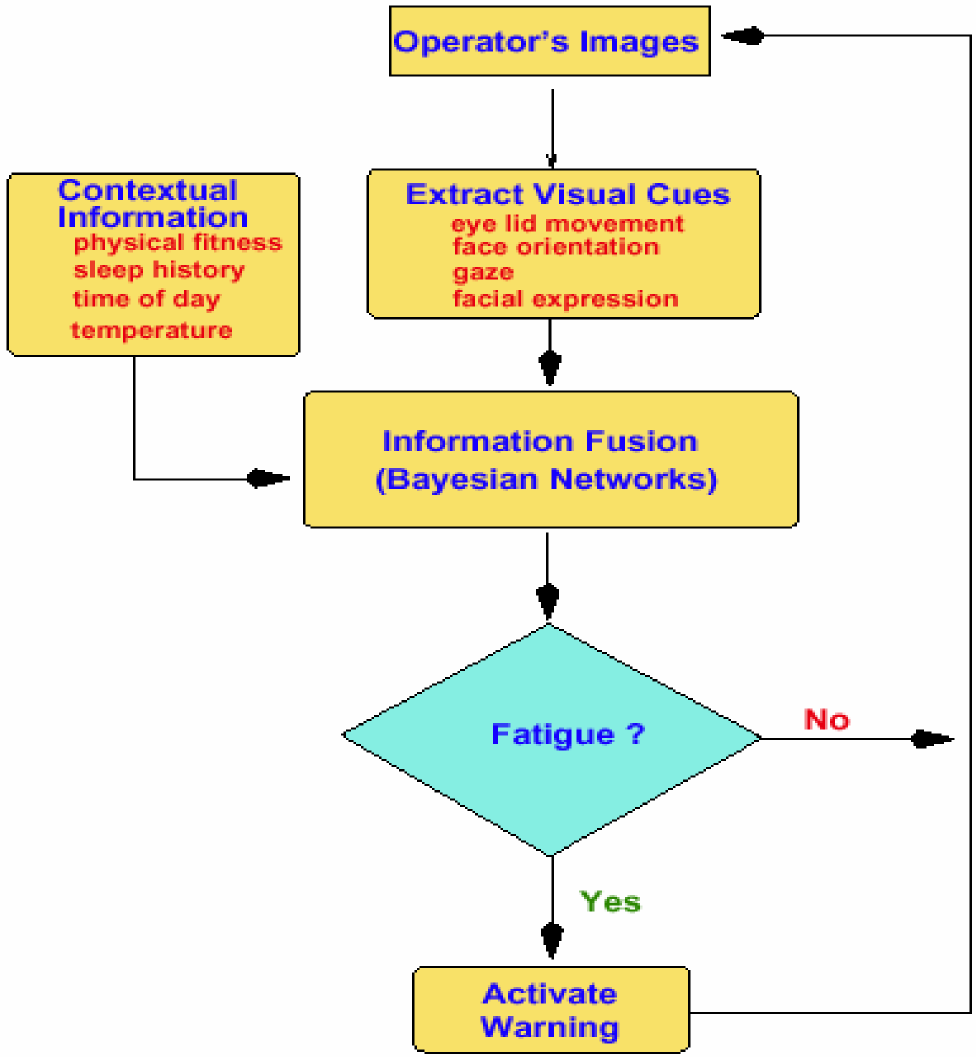
(1) A narrow-view camera focusing on the eyes

(2) A wide-view camera focusing on the face



*Picture from NY Time Business Section (C6) Aug. 26, 2003.

Proposed Approach



Visual Behaviors

Our system simultaneously monitors the following visual behaviors and computes various parameters in real time to characterize these behaviors.

- Eyelid movement
- Pupil movement (gaze)
- Head movement
- Facial expressions

Eyelid Movement

Observations: drowsy person will blink distinctly slower than when they are alert; Also, drowsy person will close their eyes for a longer time than when they are alert.

- **Eye detection and tracking:**

  Develop an eye tracking technique based on combining IR-based technique with mean-shift tracking (ICPR02,CVIU04).

  --- It can robustly track eyes under different face orientations, illuminations, head movements, and open/close eyes.

- **Eyelid movement parameters**:
  - Percentage of Eye Closure (PERCLOS)

    -- drowsy person has a longer eye closure duration than the alert person
  - Average Eye Closure/Open Speed (AECS)

    -- drowsy person will blink distinctly slower than the alert person.
  - Struggle-to-Stay Awake (SSA) Eye Blink (e.g. video demo)

Gaze (Pupil Movement)

Observations: drowsy person will have a narrow gaze region than when they are alert; Also, drowsy person will have less saccadic movements than when they are alert.

- **Gaze tracking**

Develop a robust and accurate eye gaze estimation technique (MVA04, CVPR05) based on combining

(1) Pupil location (local gaze)

Local gaze is characterized by relative positions between glint and pupil center.

(2) Head orientation (global gaze)

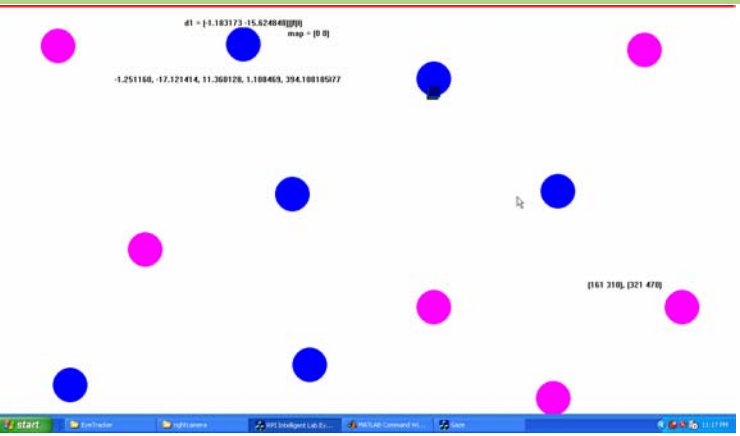
Head orientation is estimated by pupil shape, pupil position, pupil orientation and pupil size.

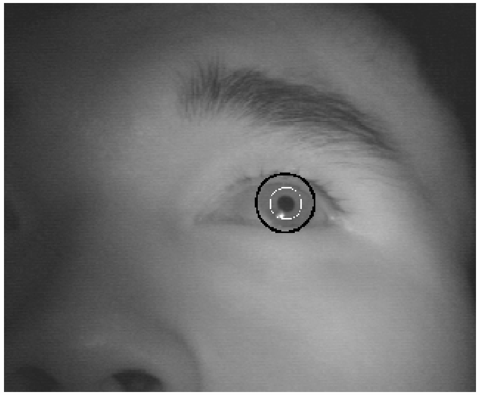
- **Gaze parameters**

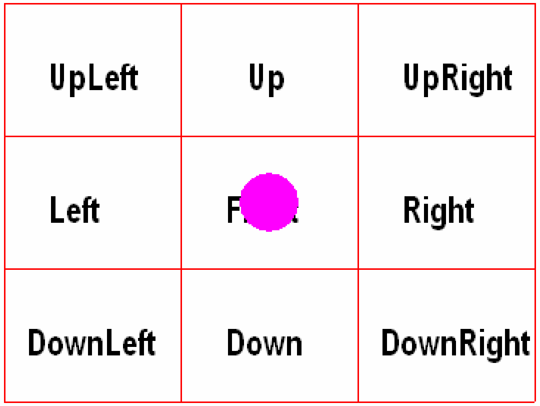
-- Percentage of Saccadic Movement (PERSAC)

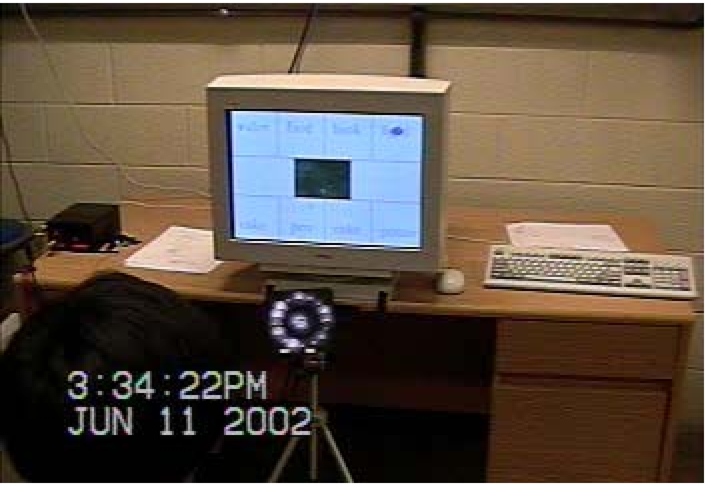
-- Gaze Spatial Distribution Over Time (GAZEDIS entropy)

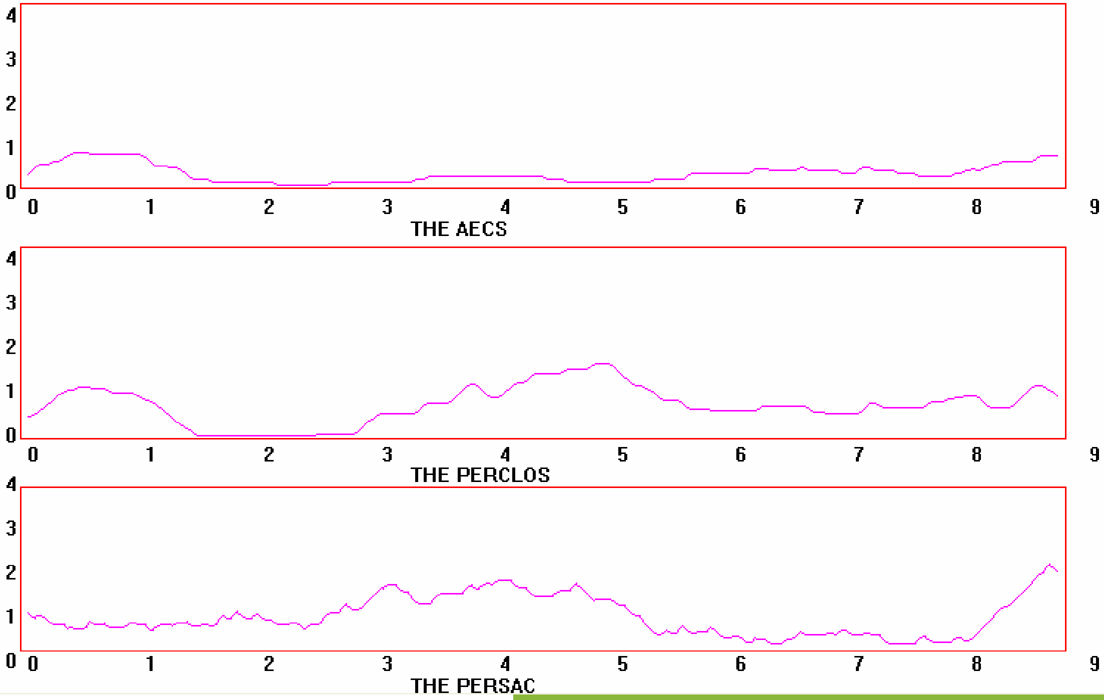
Eye & Gaze Tracking Demos











Head Movement

Observations: drowsy person will exhibit certain unique head movement such as head nodding

- **Face pose tracking** (ICPR 04, WACV02)
  Develop a real time head pose tracking technique that can perform 3D face pose estimation from a single uncalibrated camera.

- **Head movement parameter**
  -- Head tilt frequency over time (NodFreq)

Facial Expression

Observations: drowsy person will have less facial expressions and exhibit more frequent yawning

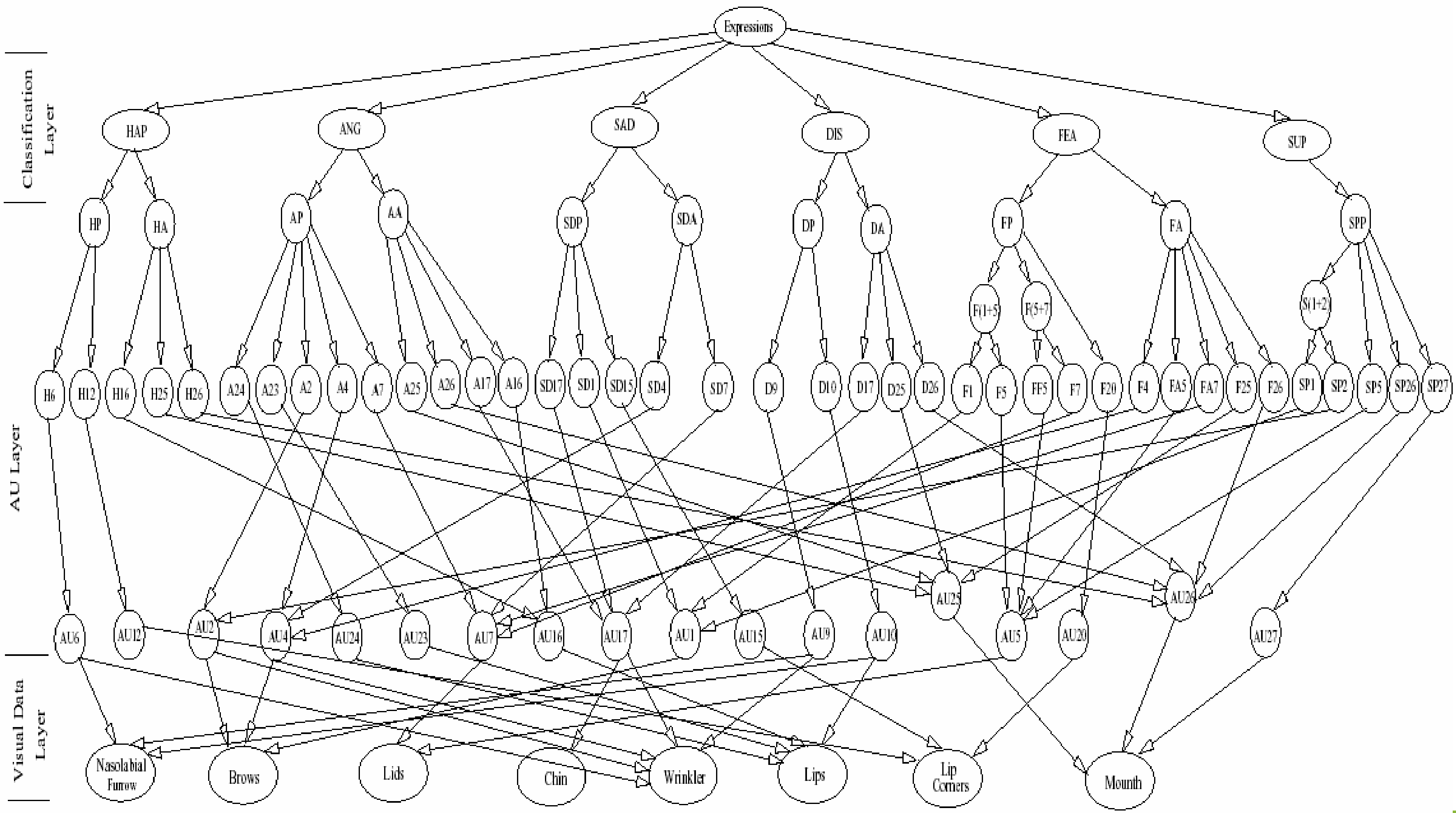
- **Facial Expression Analysis**

  Develop a real time facial feature tracking technique that

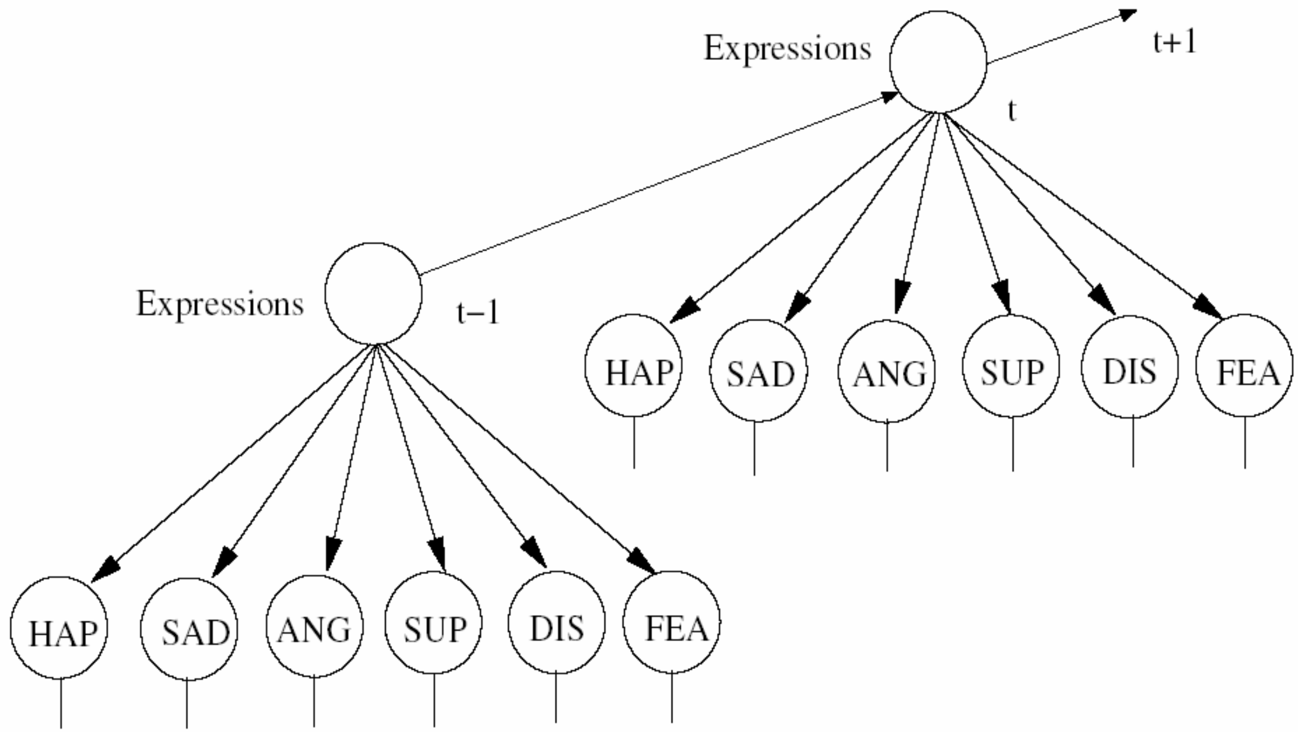
  --- Can robust detect and track facial features under head movement, self-occlusion and different facial expressions (WACV02, CVPR04).

  --- Based on the detected facial features, we try to recognize certain facial expressions (ICCV03, PAMI05) such as yawning, happy, anger, surprise, …

AU-based Facial Expression Analysis



Dynamic Modeling



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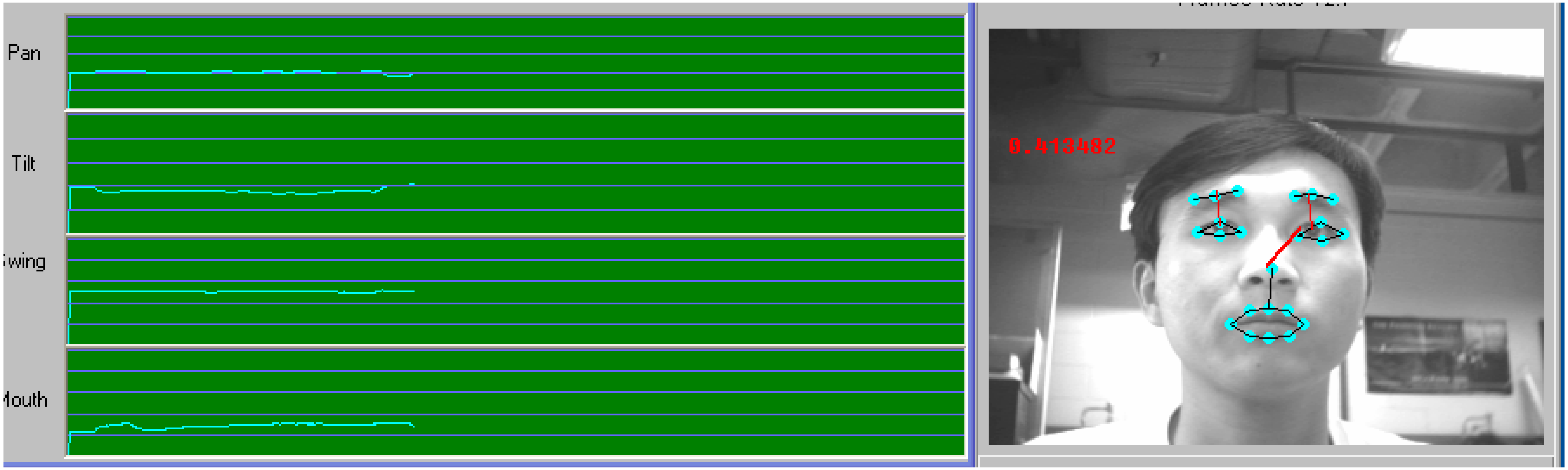
Fatigue Expressions

- Static fatigue expressions
  - Expression-less expression, seriousness expression, expressions with mouth corners down
  - Yawning expression

  --- Yawning frequency over time (YawnFreq)

- Dynamic fatigue expressions
  - expression change, especially around mouth, over time, except for the eyes

Face Pose, Facial Feature Tracking, and Facial Expression Analysis



Fatigue Modeling

- **Human fatigue generation is a very complicated process:**

  (1) Fatigue represents the affective state of an individual, is not observable, and can only be inferred.

  (2) Observations of fatigue are uncertain, incomplete, dynamic, and from different from perspectives.

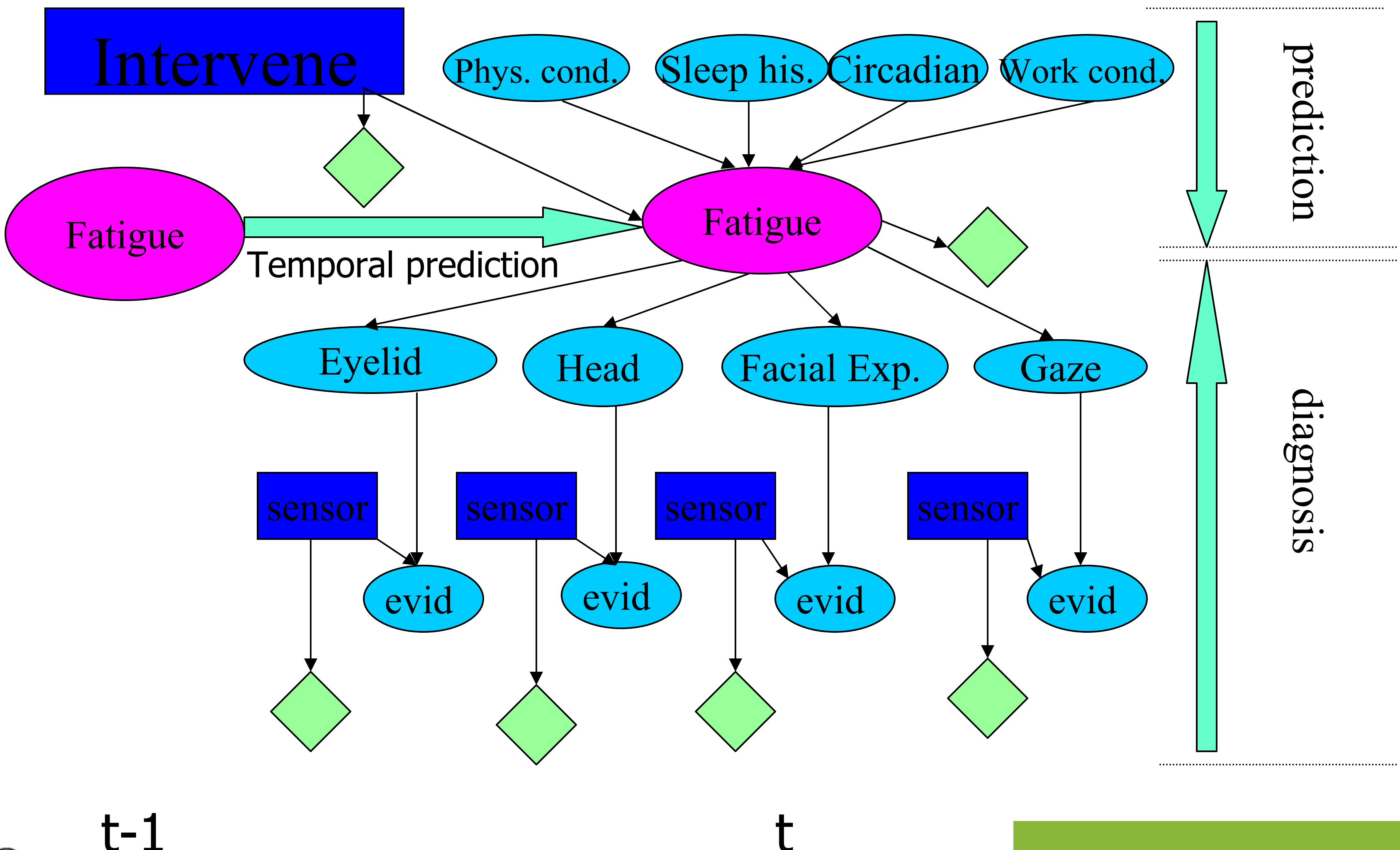
  (3) Current fatigue model is based on sleep regulation, existing a gap between fatigue and performance.

- **Propose a probabilistic framework based on the Dynamic Bayesian Networks (DBN) to**

  (1) systematically represent and integrate various sources of information related to fatigue over time.

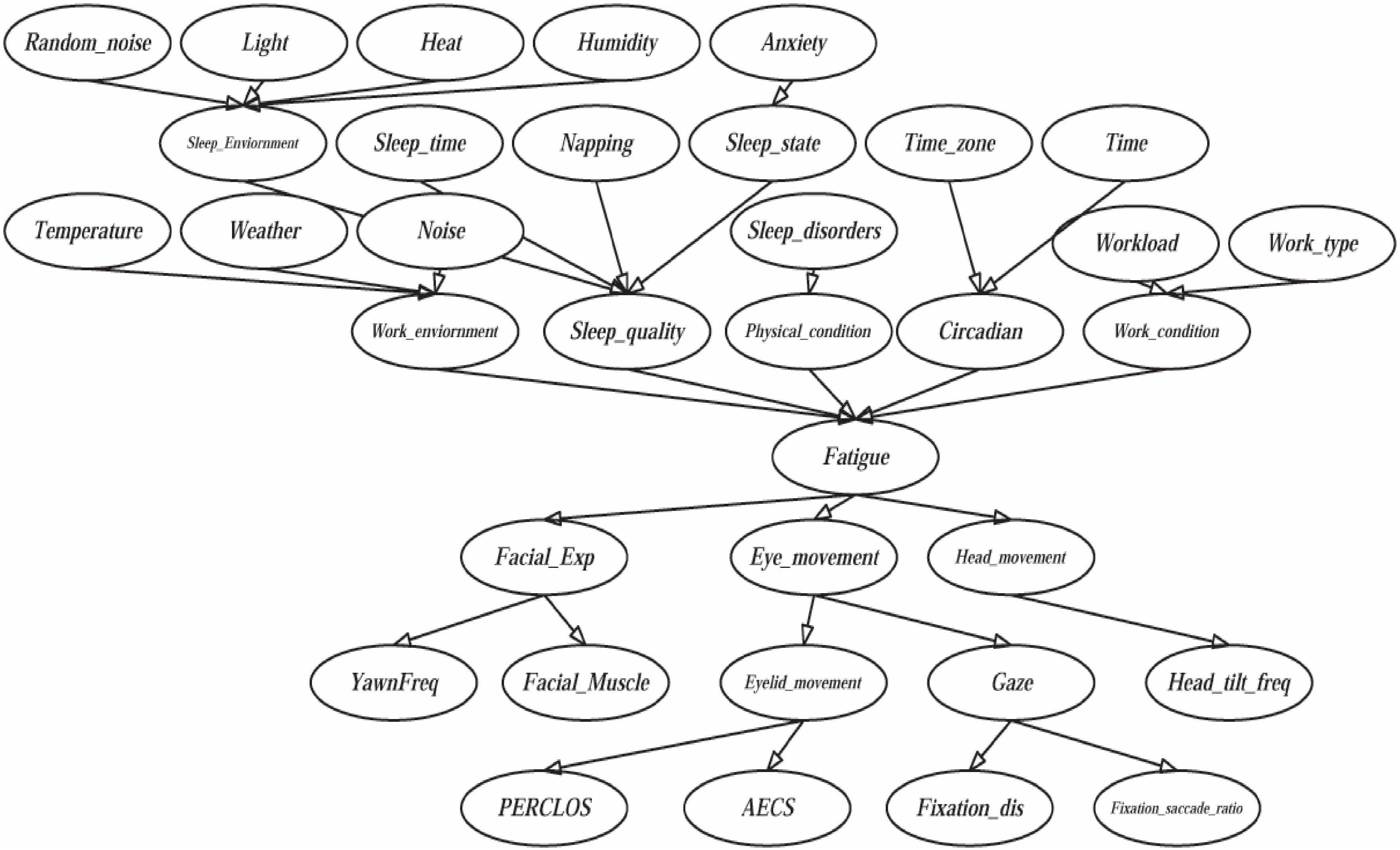
  (2) infer and predict fatigue from the available observations and the relevant contextual information.

A Dynamic Bayesian Network for Fatigue Modeling*

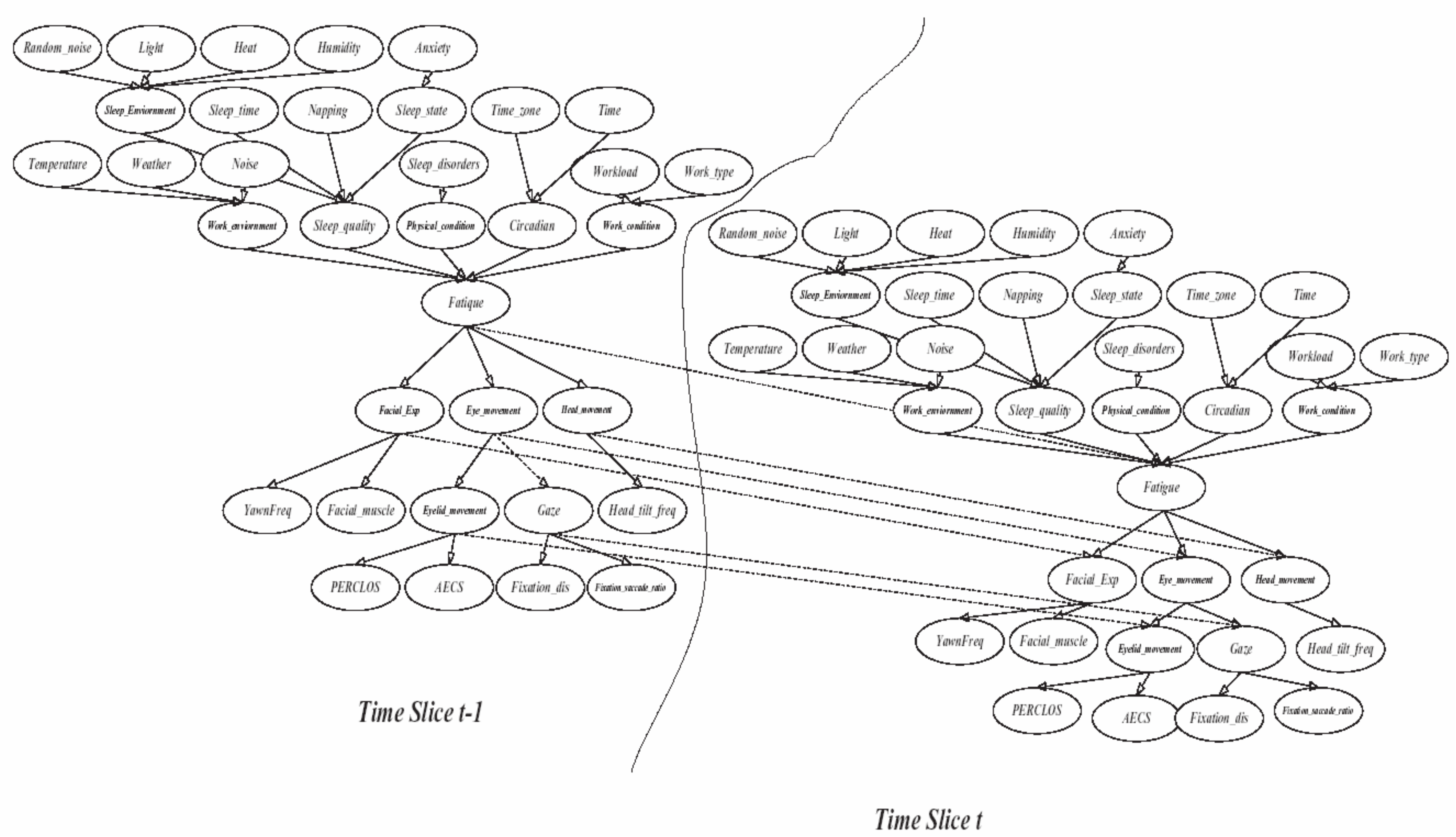


* to appear In IEEE transactions on SMC A

Bayesian Static Fatigue Model



Dynamic Fatigue Modeling



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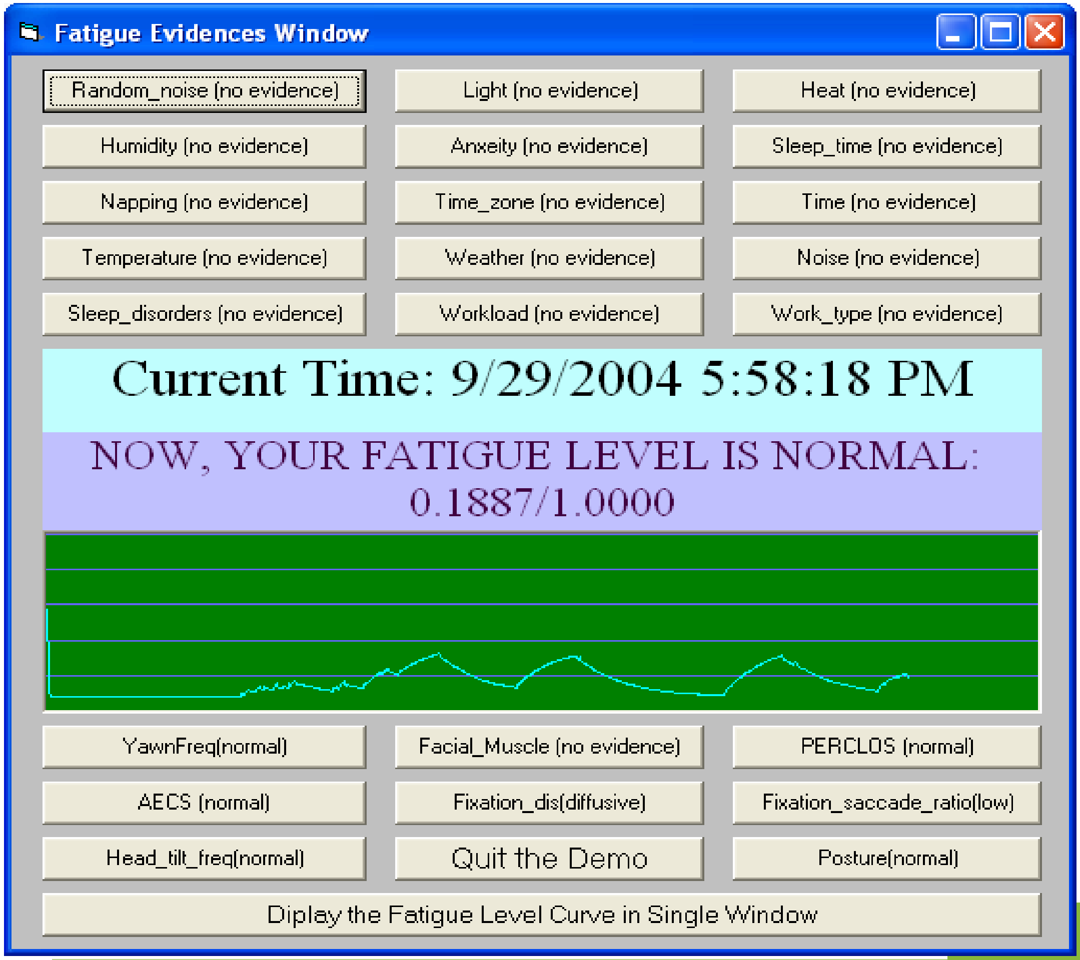
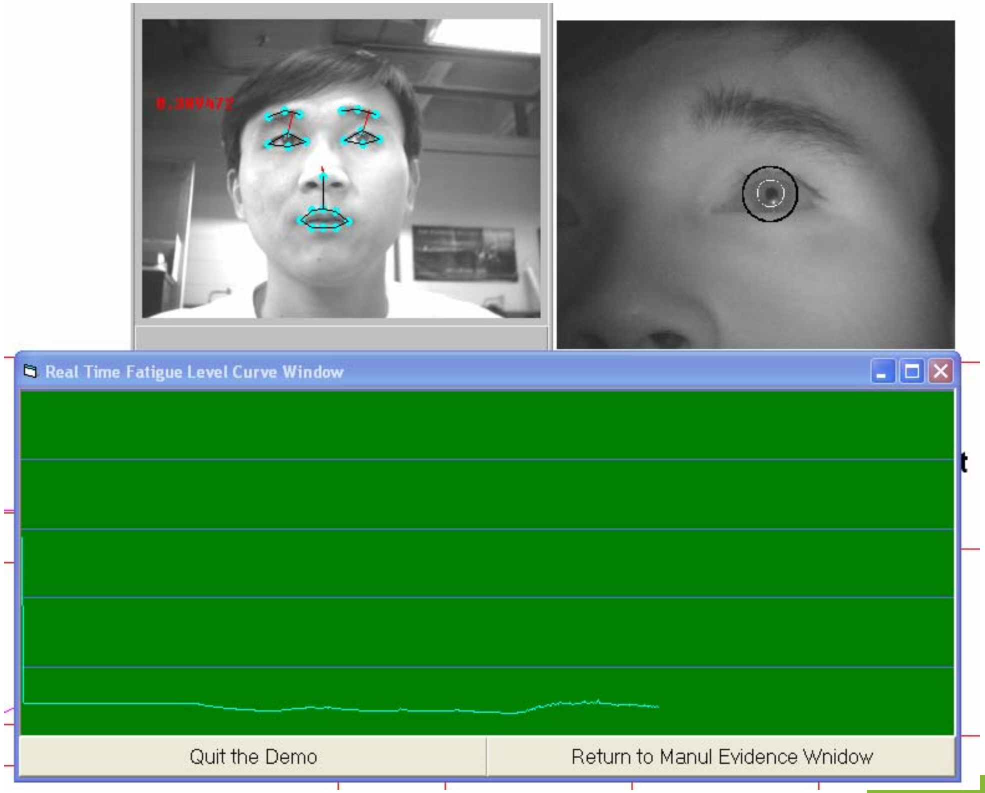
The Visual Interface

The visual interface: (1) combine the vision system and the DBN fusion system; (2) Display the composite fatigue index and issue a warning when the fatigue level is critical.



The Prototype System

The prototype system: upper right corner shows the image from the eye camera; upper left corner shows the image of face camera; bottom shows the real time plot of the composite fatigue index curve over time.

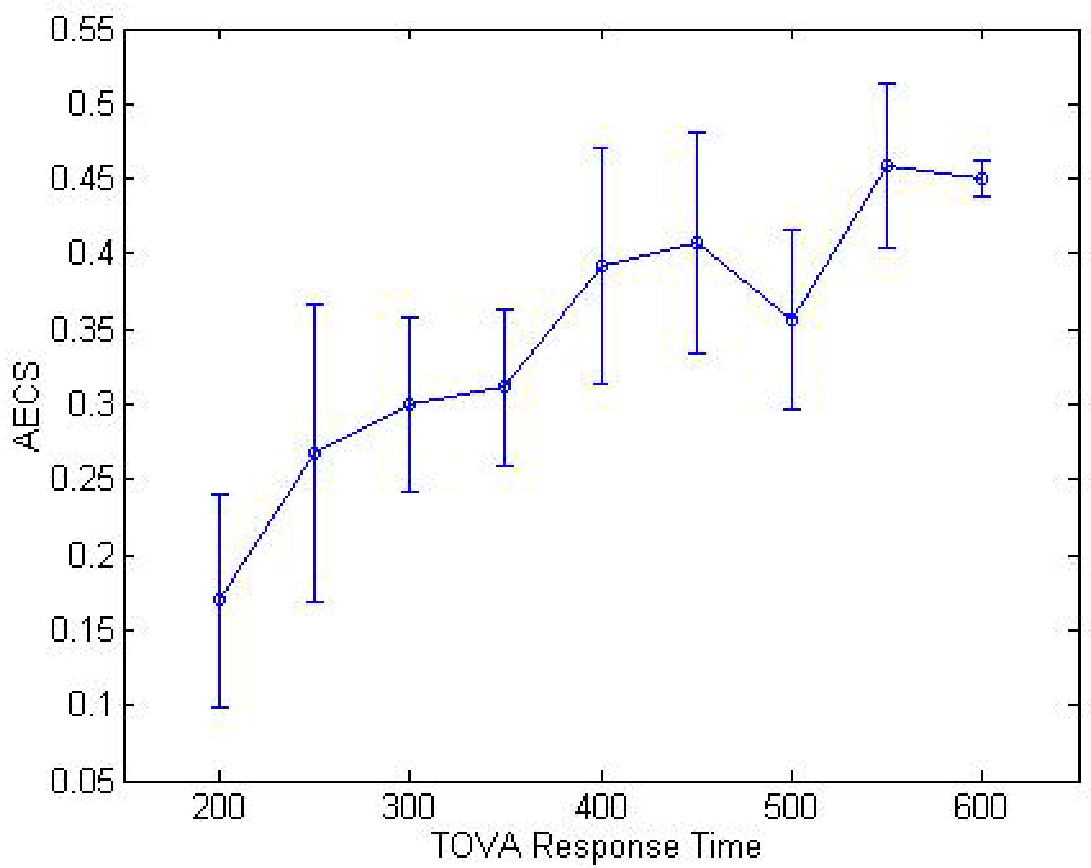


System Validation

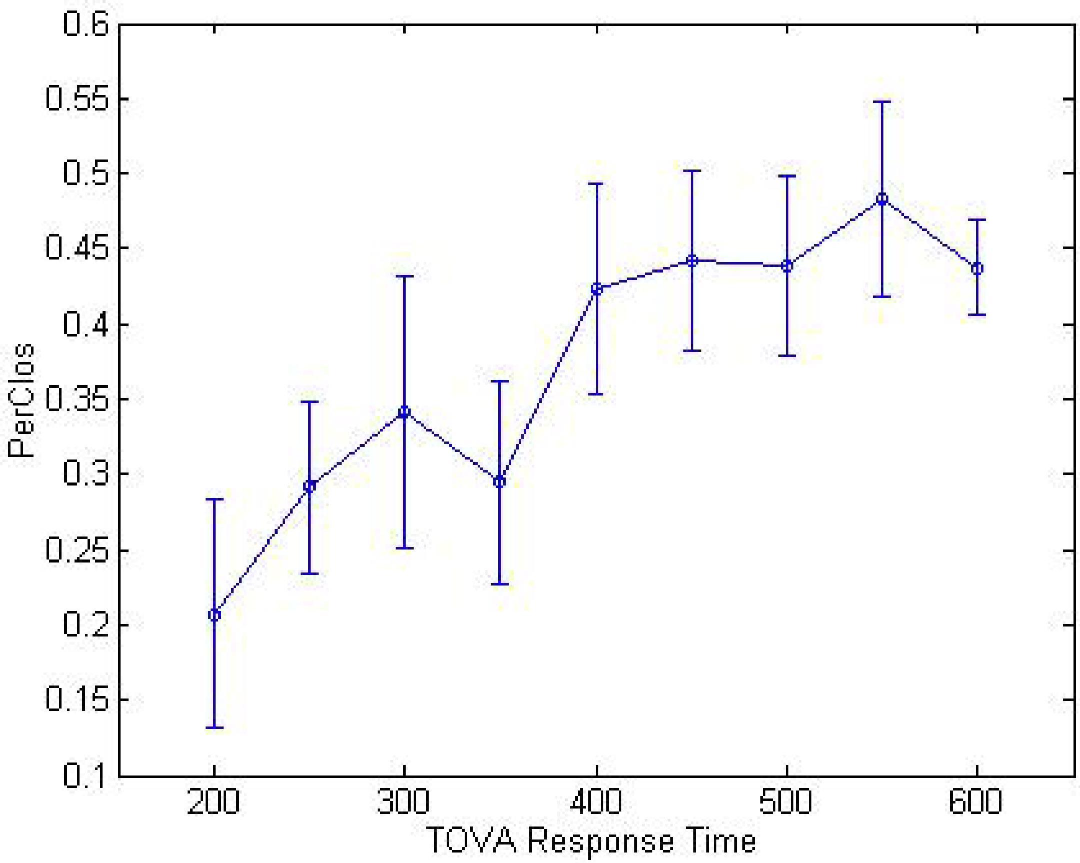
- Goal
  - study the correlation of the output of our fatigue monitor with subject performance and with other physiological measurements.
- Experiment Conditions
  - Total of 8 subjects participated in the study
  - They were deprived of sleep for a total of 36 hours
  - Two sessions of experiments were conducted: one at 9:00 pm in the evening and the other 6:00 am in the morning, with each session lasting 20 minutes
  - Subjects perform TOVA vigilance test for each session
  - Measurements recorded: EEG, EOG, visual measurements, performance measurements (response time, errors, ..)

Experiment Setup

Average Correlation-AECS



Average Correlation-PERCLOS



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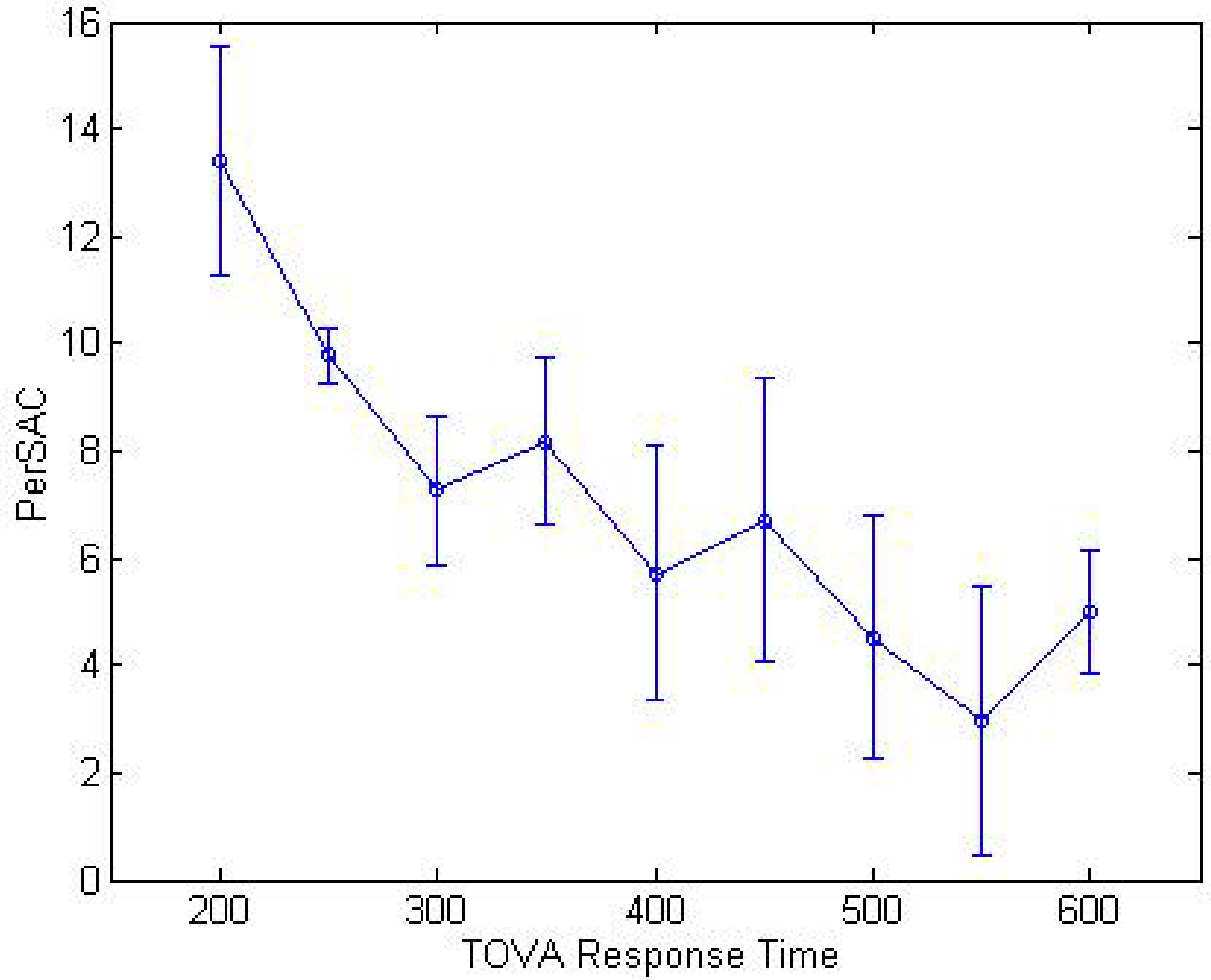
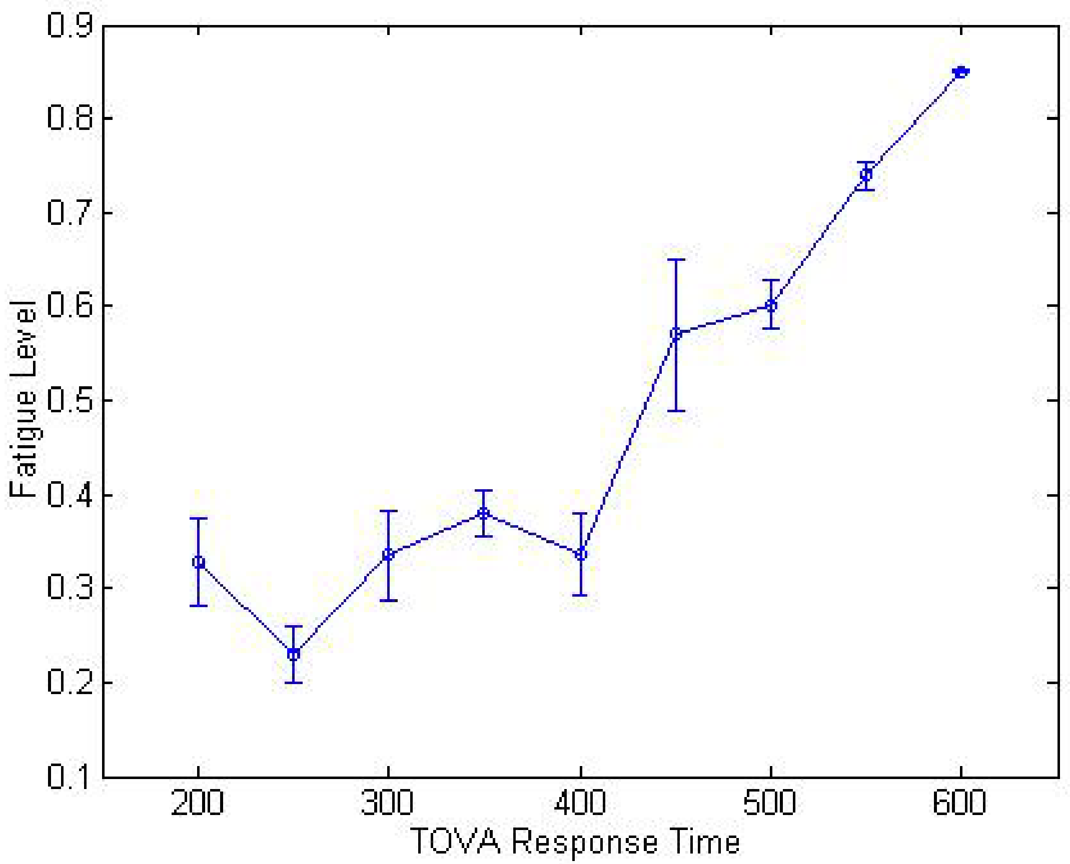
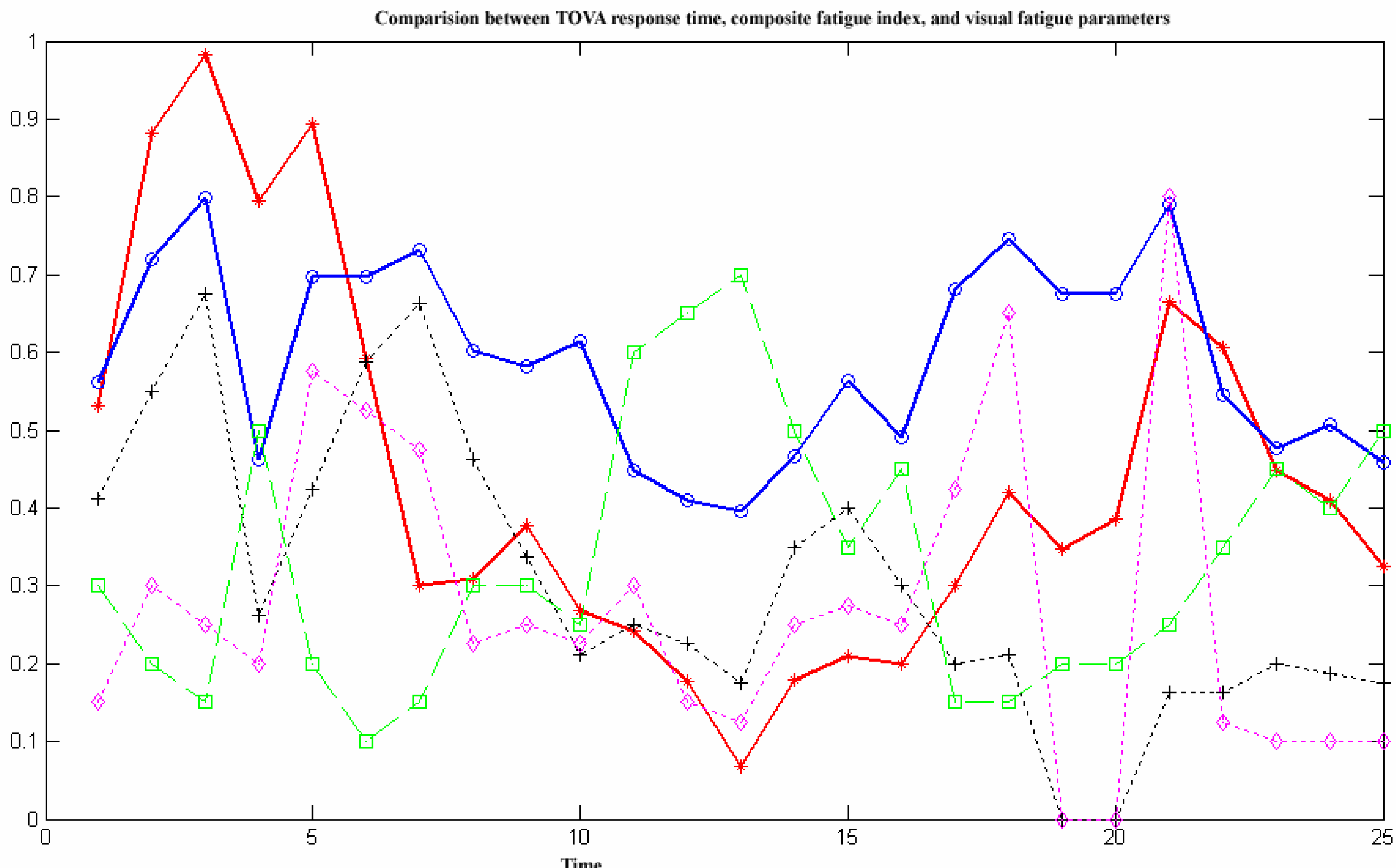
Average Correlation -PERSAC



Average Condition-Composite



On-line Prediction: Composite Fatigue Score v.s. Individual Parameters



Red : TOVA response time
Blue: Inferred fatigue level
Black: PERCLOS
Green:PERSAC
Purple: AECS

Average v.s. online prediction

- Fatigue Data Analysis (Response time is used to represent fatigue level)
- Average condition correlation

	AECS	PerClos	Persac	Inferred fatigue level
Response time	0.9284	0.9021	-.8907	0.9343

- Online prediction correlation

	AECS	PerClos	Persac	Inferred fatigue level
Response time	0.3850	0.5443	-.4806	0.7213

Conclusions

- Developed non-intrusive real-time computer vision techniques to extract multiple fatigue parameters related to eyelid movement, gaze, head movement, and facial expression.

- Developed a probabilistic framework based on the Dynamic Bayesian networks to model and integrate contextual and visual cues information for fatigue detection over time.

- Validate the prototype fatigue monitor through a human subject study.

Conclusion (Cont'd)

- The validation shows that under average condition with careful data pre-processing, PERCLOS is highly correlated with fatigue (response time).

- But the correlation reduces significantly under real tracking condition without much pre-data processing.

- In both average and real tracking situations, the combined fatigue score outperforms the performance of each single parameter.

This is especially true for the real tracking case. This demonstrates the importance of combining multiple parameters for real world fatigue prediction.

Conclusion (cont'd)

- We have developed the core technologies for real time and non-intrusive human fatigue monitoring.

- We are looking for collaborations with industry to commercialize our technologies.