A collaboration between psychologists and engineers.

**Perception-Based Engineering: Integrating Human Response Into Product Design**

To integrate into the design of engineering systems, the ways in which people perceive, and are affected by, machinery outputs.

*Printer Example*

- Image-Quality/Speed/Cost
- Noise/Vibration/Air-Quality/Heat
- Comfort/Job-Performance/Behavior

http://widget.ecn.purdue.edu/~pbe
Cognitive Psychology and Engineering

Cognitive psychology is concerned with all processes by which the sensory input is transformed, reduced, elaborated, stored, recovered and used.

Acquiring information (perception, attention)  
Maintaining information (memory)  
Communicating information (language)  
Utilizing information (reasoning, problem solving, decision making).

Engineers design machines that produce stimuli that affect people. Also interested in efficient information processing.
Perception-Based Engineering

Automotive Industry Example:

Engineering Model

- Engine
- Exhaust Components
- Wind
- Road
- Ambient Light
- Air Temperature
- Humidity
- Chemicals

Perception Model

- stimuli e.g.,
- noise
- vibration
- temperature
- humidity
- chemicals
- images

 biases

Customer Perception of, e.g., overall Vehicle Quality, or climate control
Perception-Based Engineering

Engineering Models: sources to stimuli. For example, combustion noise and vibration → structural paths → noise in car
sign + lighting → windows → image seen by driver

Perceptual and Decision Making Models. For example, noise → noise attributes and their strengths → sound quality
expectation, context, biases ..... temperature + humidity → thermal comfort

Quality of Vehicle Interior Environment
Example Attribute Model - Tonality

Aures's Model: Bandwidth

\[ w_1(\Delta z_i) = \frac{0.13}{\Delta z_i + 0.13} \]

Aures's Model: Frequency

\[ w_2(f_i) = \left( \frac{1}{\sqrt{1 + 0.2(f_i/700 + 700/f_i)^2}} \right)^{0.29} \]
Aures's Model: Prominence

\[
\Delta L_i = L_i - 10 \log_{10} \left\{ \sum_{k \neq i} A_{E_k}(f_i) \right\}^2 + E_{Gr}(f_i) + E_{HS}(f_i) \]

Masking by other tones  Masking by noise  Threshold

Combining the Tonal and Noise Components

\[
w_T = \sqrt{ \sum_{i=1}^{n} [w'_1(\Delta z_i)w'_2(f_i)w'_3(\Delta L_i)]^2 } \\
w'_n = w_n^{1/0.29} \\
w_{Gr} = 1 - (N_{Gr}/N) \\
\text{Tonality} = c \cdot w_T^{0.29} w_{Gr}^{0.79}
\]
Example “Decision” Model - Noise Annoyance

- **Inputs**: sound attributes (Loudness, Sharpness, Roughness, Fluctuation Strength)
- **Outputs**: average annoyance ratings
- **Structure**: two hidden layers 4 - 9 - 6 - 1 nodes
- **Data**: simulation for pre-training, 28 people’s response to 700 sounds.

![Diagram of the model](image)
People-based Criterion Example (CE & ME): Road Smoothness or Roughness Evaluation

- Road Construction Equipment
- Profilometer
- Road-Tire Models
- Road Induced Noise
- Structural- and Acoustic-Path Noise Prediction Model
- Seat-Occupant Vibration Model
- Driver or Passenger Perceptual Processes
- Perception of Roughness or Smoothness
- Roughness Index
- Measured Road Profile
- Road Profile

Road Induced Vibration
Tire to Seat Rail and Steering Wheel Vibration Model
Occupant Vibration
Noise Heard by Occupant
Roughness Index
Perception of Roughness or Smoothness
PBE - Faculty and Departments

Civil Engineering
Andrzej Tarko, Highway Safety and Design
Jon Fricker, Driver Performance, Transportation Planning

Electrical & Computer Eng.
Hong Z. Tan, Haptics, Vibration Quality
Jan P. Allebach, Ed Delp and Charlie Bouman, Image Quality
Mary P. Harper and Leah H. Jamieson, Speech Communications
Thomas M. Talavage, Functional Magnetic Resonance Imaging
Dave Ebert, Graphics and Displays

Industrial Engineering
Barrett Caldwell, Performance in Time-Critical Environments
Mark Lehto, Decision Making
Mechanical Engineering

James E. Braun, HVAC, Thermal Comfort
Yan Chen, HVAC, Air Quality
George T-C Chiu, Image Quality, Touch Interfaces, Ride Quality
Patricia Davies, Sound Quality, Vibration
Dan Hirleman, Texture

Psychological Sciences

Greg Francis, Vision Perception, Cognitive Modeling
Ian Neath, Modeling of Decision Making, Memory
Zygmunt Pizlo, Image Perception, Cognitive Processes Modeling
Aimee M. Surprenant, Cognitive Processing, Noise Effects
Robert Proctor, Human Factors and Performance

Dave Pick (Calumet), Multiple Task Performance, Driving
Glenis Long (CUNY), Psychoacoustics, Sound Quality
image perception
sound and vibration quality
speech processing: speech and gesture
touch and feel interfaces
texture
thermal comfort and air quality
multiple stimuli, e.g., noise and vibration; driver assistance systems; touch, vision and acoustic
performance, e.g., drivers and age effects decision making in adverse environments
Sample Projects in More Detail........
Research goal: to investigate the integration of visual and haptic information in the context of multimodal interfaces.

Example: When tapped on the shoulder, people naturally turn their attention to that location.

Hypothesis: An observer might find a visual change faster if tapped on the back in the corresponding quadrant?
Perception of Continuously Variable Transmission Performance

Human Performance Laboratory

Profs: Robert Proctor (Psych), Dave Pick (Psych), Jon Fricker (CE).
Student: Dong-Yuan (Debbie) Wang (Psych);

Test Track Experiment:
Examine effects found in results of previous research
Ex 1: The role of sound in perception of CVTs
Ex 2: Response to visual and acoustic information
Ex 3: Identifying factors that may reduce negative perceptions of CVTs
Ex 4: Influence of “education” on CVT perception
Vibration Quality

Professors: George Chiu (ME), Hong Tan (ECE), Zyg Pizlo (Psych)
Student: James Mynderse (ME)

What are the perceptual attributes of vibration?

**Sound:** loudness, spectral balance (sharpness), tonalness, impulsiveness, fluctuation, roughness

**Vibration:** rough? tingly? strong?......

How can we predict them from measured vibrations?

**Project Goals:**

designing and building a test rig for studying hand-arm vibration response

establishing thresholds and/or sensitivity curves for hand-arm vibration.
Sound Quality and Quantification of Speech Intelligibility for Aging Drivers

Professors: Aimee Surprenant (Psych), Patricia Davies (ME)
Student: Meghan Saweikis (Psych)

By 2030: 30% of US population > 55 yrs old.

Speech Perception in Noise:
Psychoacoustic Testing
SPIN Tests - Interior Noise

Speech Intelligibility Index:
Correlation with Metrics
SII [ANSI 1997] includes hearing thresholds, sufficient?

Speech Intelligibility and Sound Quality Issues
SI and SQ linked?
Sensory and intellectual performance decline substantially as people age.

Figure 1. Cross-sectional age gradients for vision, hearing, five intellectual abilities, and the intellectual ability composite ($N = 315$, age range = 25–101 years). Linear and quadratic age trends are reported in the top rows of Table 1. With respect to vision and reasoning, quadratic age trends did not differ significantly from zero ($p > .01$). Intel. Ability Comp. = intellectual ability composite.
**Sensory and intellectual performance**

**Vision**
- binocular distance acuity; left and right eye close visual acuity

**Auditory**
- composite of pure tone; speech reception threshold; masking

**Perceptual speed**
- digit letter test; digit symbol substitution; identical pictures

**Reasoning**
- figural analogies; letter series; practical problems

**Knowledge**
- practical knowledge; spot-a-word; vocabulary

**Memory**
- Activity recall; memory for text; paired associates

**Fluency**
- naming animals and letters
Speech Recognition Research
Mary Harper & Leah Jamieson, ECE and Aimee Surprenant - Psych.

- Speech Recognition Systems, Natural Language Processing, Language Perception and Understanding
- Speech, Gesture and Gaze Group http://vislab.cs.wright.edu/KDI/
Effective communication of information through graphics rendering, modeling, abstraction, animation, and perceptualization.

- **Procedural techniques**: algorithms to generate complexity and realism → reduce data transmission

- **Understanding the limits of human vision and perception**: what is necessary to show what computations can be avoided
Printer Design and Image Perception
J. Allebach (ECE), Z. Pizlo (Psych), G. Chiu (ME)

Human Perception

Image Quality

Printing/Imaging System

Human Visual System

Printer Model

Image Processing

Printing Process

Printer Controller
Image Quality Metrics

Typical engineering metrics do not provide adequate measure of perceived image fidelity.

\[
\sum_i \sum_j \frac{(C(i,j) - A(i,j))^2}{N} < \sum_i \sum_j \frac{(B(i,j) - A(i,j))^2}{N}
\]

But "I" feel B is better than C!
Image Fidelity Assessor (IFA)
A model of the human visual system designed to evaluate perceived image fidelity.

Original

Distorted

IFA

The likelihood that people will perceive a difference between the two images

Image Fidelity Assessor

Distortion Map

C. Taylor, Z. Pizlo, J. Allebach
Perception-based Engineering

"Parenthood" Statements

Goals:

• To make people’s lives better...
  more efficient, more enjoyable, more access, safer

• To make better machines and engineered systems
  Embed clever human information processing into machines.
  Make machines that improve people’s lives.

Worries:

Sometimes too much focus on product user (purchaser) without consideration of product “victims”
Perception-Based Engineering Group

- Based on many collaborations between professors and students in Psychology, AUS and Engineering.

- Inherently multi-disciplinary, psychologists value engineers’ expertise, and engineers value psychologists’ expertise.