

Haptic State Estimation

Estimating pilot state within a haptic flight control system

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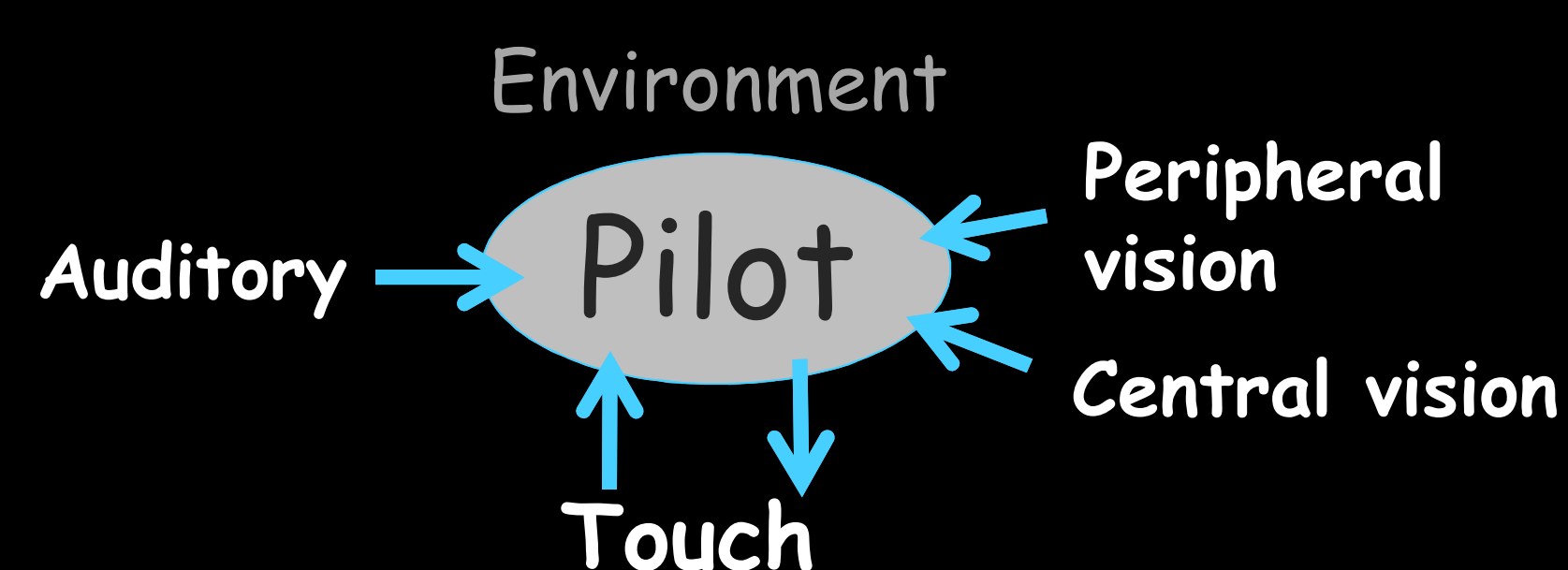
Objectives, 2009

- Evaluate feasibility of inferring aspects of pilot state using active (force-feedback) side-stick
 - Contact with stick (haptic monitoring)
 - Desire to change automation support level
 - Pilot workload
 - Stress
- Conduct human-in-the-loop experiment to generate database for off-line investigation of potential signals and identification methods

Background -- Haptics and Haptic Flight Control

Haptics

- Sense of cutaneous touch and movement and force signals from joints, muscles
- Only bi-directional sense; natural manipulation of physical environment



Haptic Flight Control System (HFCS)

- Integrated interface for all levels of control & trajectory automation

Objective: Fluid, mixed initiative human-automation interaction over timescales between ~.1sec (handling qualities) and ~ 10 minutes (tactical decision making and maneuvering)

- <0.1 sec: domain of pure automation
- >10 min: conventional, serial human-automation interaction



Automation management integrated into primary controls and displays

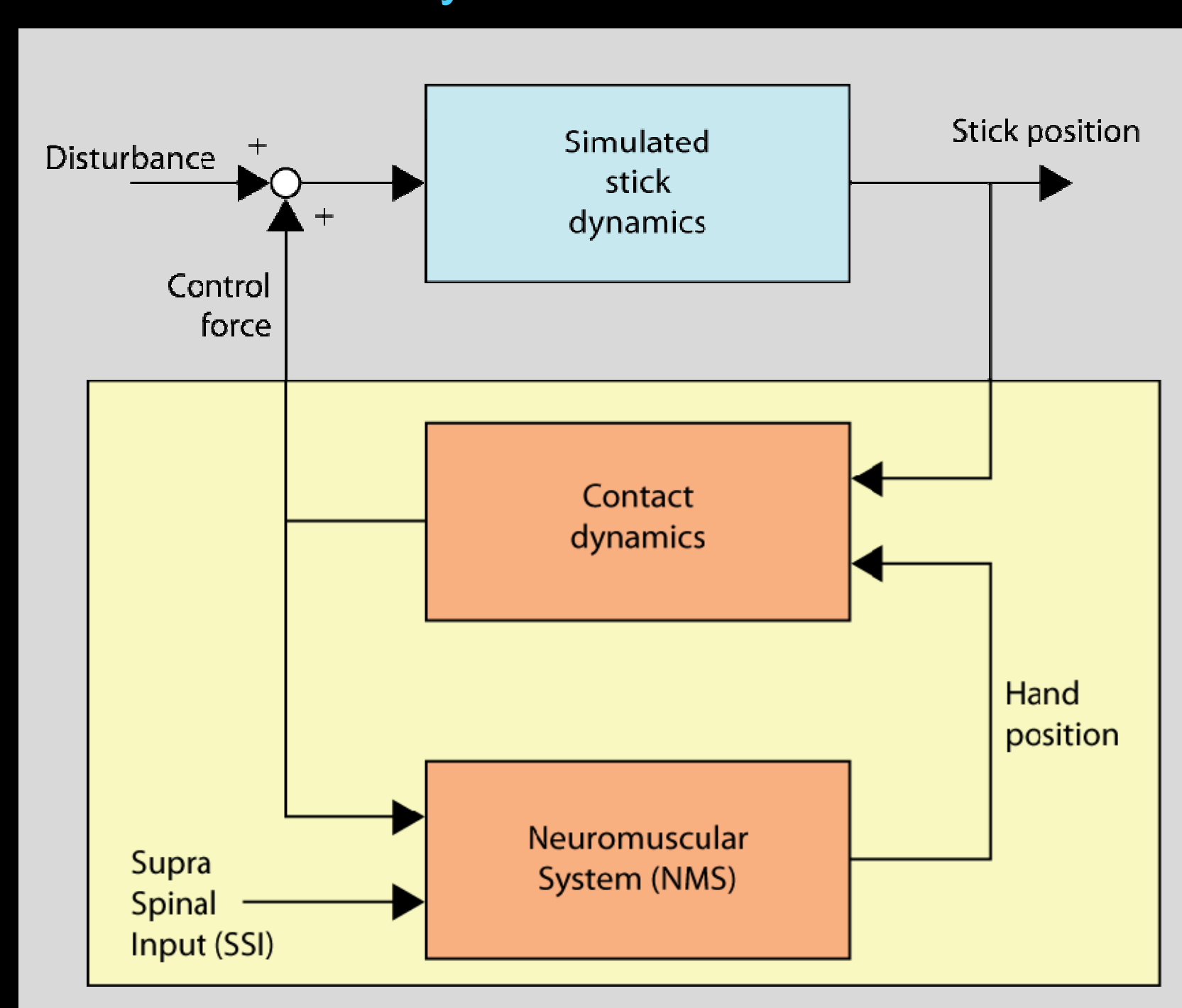
- Automation's "world view" part of pilot's primary instrument scan
 - What it perceives
 - What it's doing / going to do / can do / won't do
- Same skills used for manual and auto-flight
- Same interactions used to for manual and auto-flight management
- Pilot and automation maneuver using shared active haptic Inceptors (e.g. active stick and throttle)
- Pilot kept "in-the-loop" by interaction designed to nominally include regular, but simple inputs during action sequencing & path transitions
- Interaction design also facilitates crew-state monitoring and engagement management

Applications of Haptic State Estimation

- Desired HFCS support level (intensity) will vary depending on pilot state and outside influences, such as route changes
- A stressed or unaware pilot may require different system dynamics or feedback - not limited to haptic feedback - for optimum performance compared with a relaxed / aware pilot
- Pilot state can be logged (in the black box) for later evaluation
- Part of broader pilot state estimation system

Theory and Hypotheses

- Simplified dynamic model of neuromuscular and contact dynamics



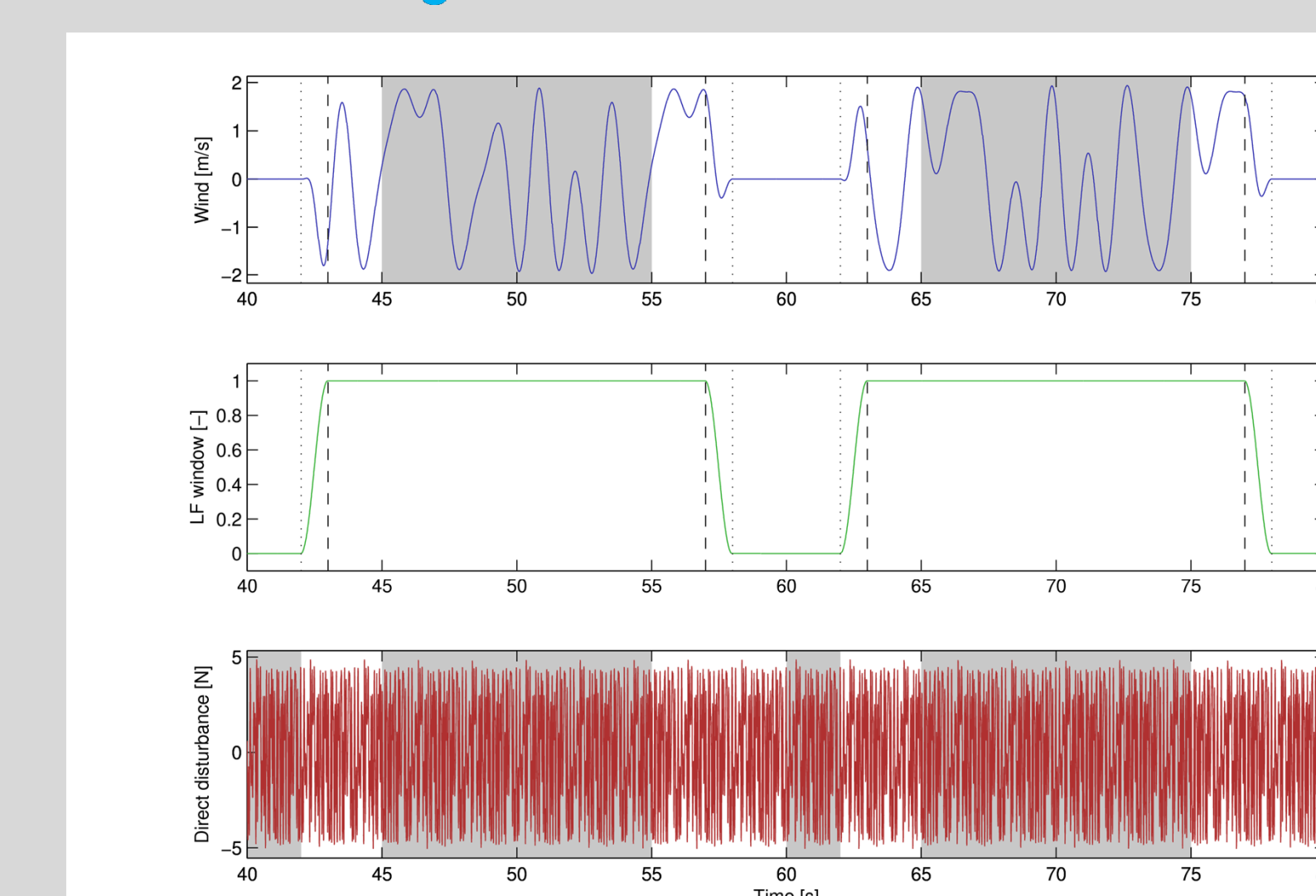
Hypotheses:

- Both stress and desire to reduce haptic support increase grip strength, which leads to more stiff / less dampened contact dynamics and thus an increased resonant peak
- Desire to reduce haptic support decreases low frequency admittance
- Desire to reduce haptic support increases applied force
- Stress/high workload leads to less linear control behavior

Implementation

- Low amplitude, multisine excitation signal injected via active stick to excite contact and neuromuscular dynamics

Disturbance signals



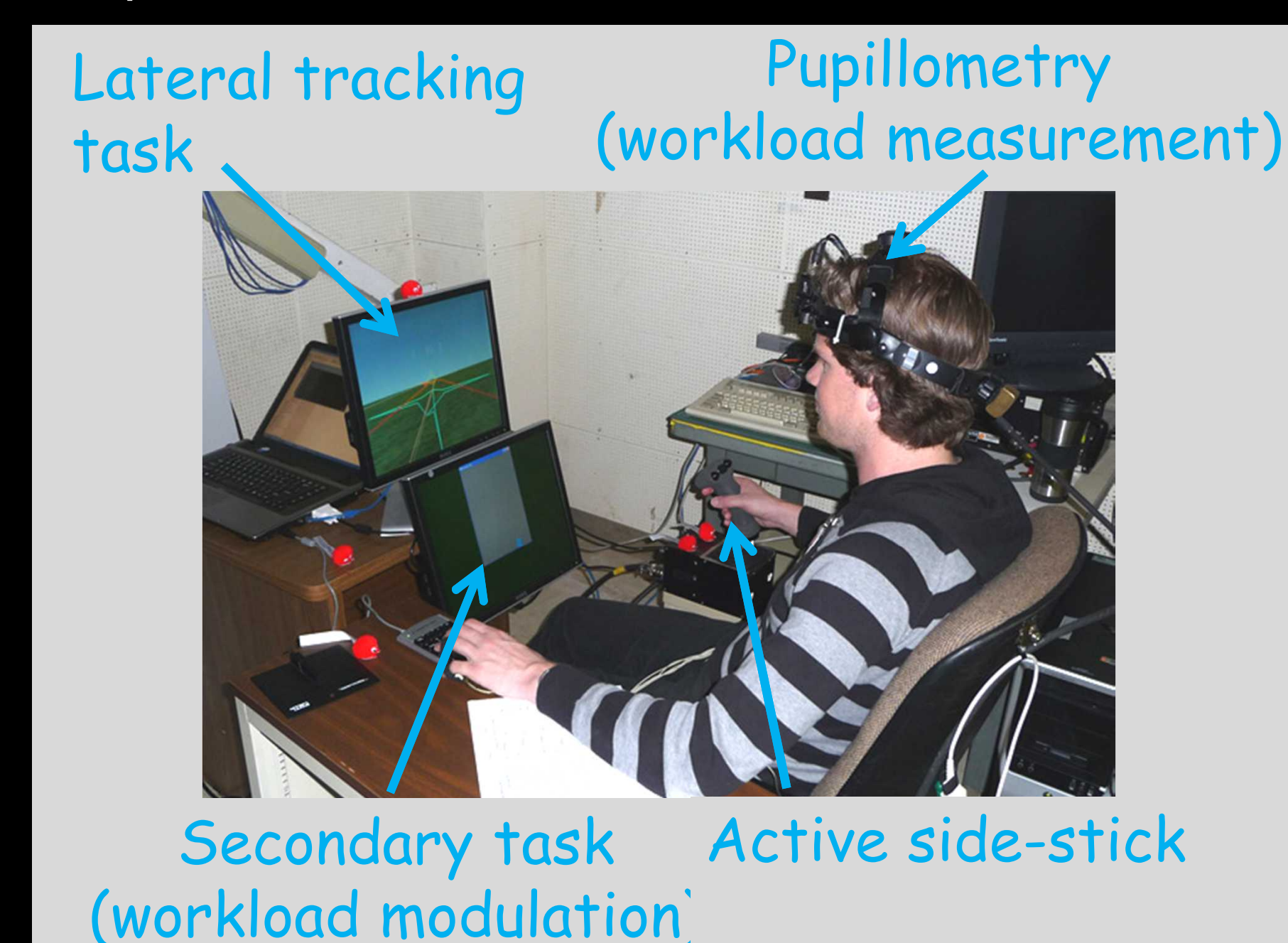
Haptic Stick



- Software controlled force/feel
- Automation back-drives stick and maneuvers aircraft by commanding stick's trim position
- Pilot can modify maneuver by moving stick from trim (final stick position = command to inner loop)
- Multisine superimposed on nominal force-feel characteristics

Human in the Loop Experiment (March 2009)

Setup



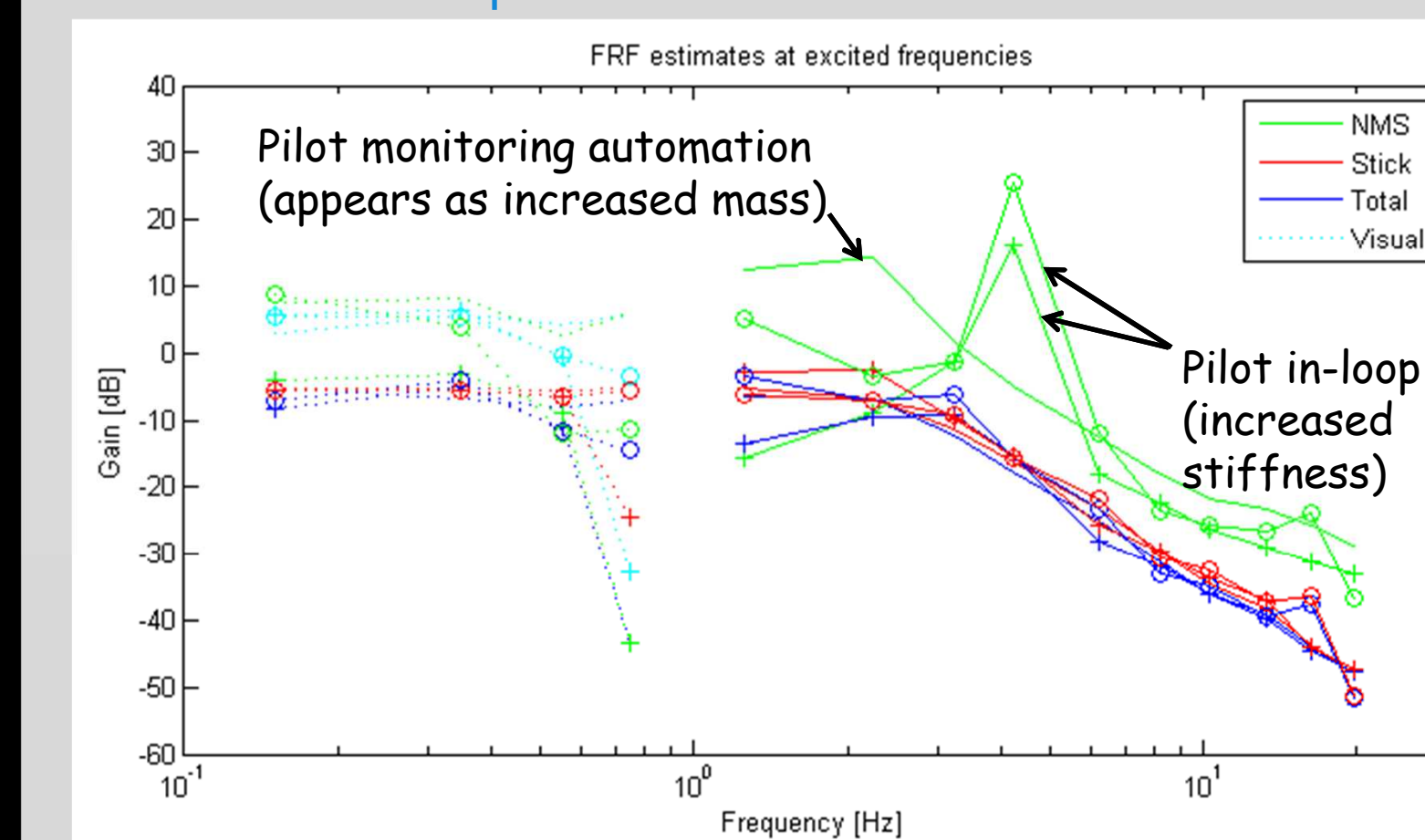
Procedure

14 Subjects participated, ~ 4 hours per subject

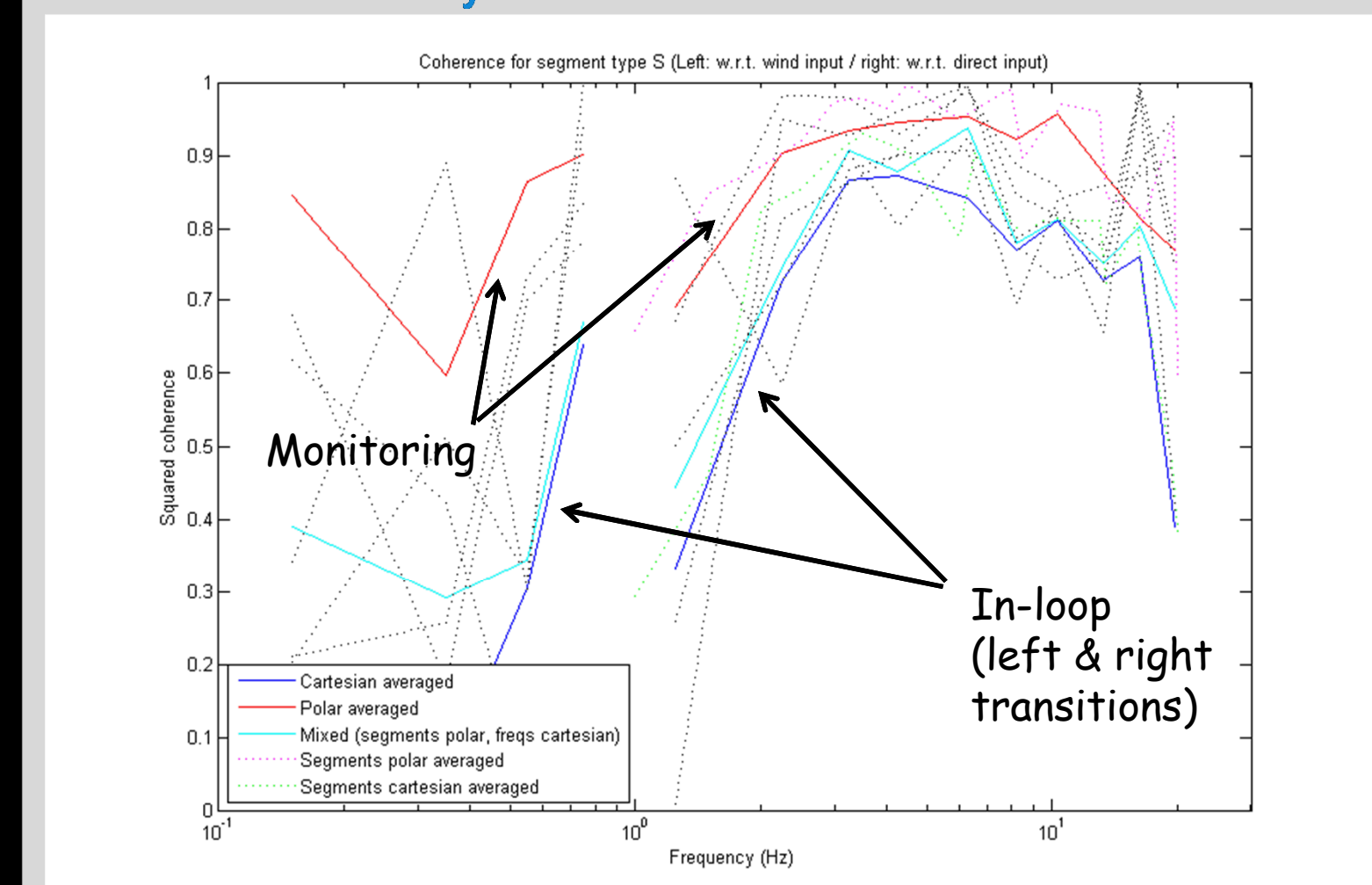
- Brief subjects about goals and objectives
- Entry questionnaire
- Attach physiological equipment (heart rate skin conductance, pupillometry (pupil diameter))
- Training (lateral control and secondary task, NASA-Task Load Index (TLX) scale and subject comment card)
- Test Matrix
 - Subjects track pseudo-random, lateral "highway in the sky" with portions overlaying and departing from automation's path (departure segments induce human-automation conflict)
 - Excitation signal amplitude, 4 levels
 - Secondary task (total task demand), 3 levels
- Exit questionnaire & remove physiological equipment

Preliminary Results

Clear resonance peak



Reduced linearity



Conclusions

- Haptic state estimation found to have promise, particularly for detecting haptic monitoring and desire to reduce control system support level, but more work needed to allow real-time op.
- Future work will focus on high-frequencies
 - Considered unobtrusive by subjects