Multimodal Sensor

This document covers the full sensor suite used in our anxiety detection study. We use a multimodal setup combining eye tracking, heart rate variability (HRV), galvanic skin response (GSR), video recording, and motion capture to pick up physiological markers of anxiety during psychometric testing.

The hardware includes 10 devices across five modalities, plus 2 software platforms for facial behavior analysis. Each device was chosen for measurement quality, wearability, and compatibility with simultaneous multi-sensor recording.

2. Eye Tracking Sensors

Eye tracking captures gaze position, fixation patterns, saccade dynamics, pupil dilation, and blink rates. These are all sensitive to cognitive load and anxiety.

2.1 Pupil Labs Core

Type: Head-mounted eye tracker

The Pupil Labs Core is an open-source, research-grade head-mounted eye tracker. It uses dark pupil detection with a 3D eye model for gaze estimation across varying lighting. The system supports binocular tracking at 200 Hz.

Parameter	Specification
Detection	Dark pupil + 3D eye model
Calibration	5-point
World Camera	1080p @30 Hz, 720p @60 Hz, 480p @120 Hz
Eye Camera	200 Hz binocular
Connectivity	USB-C
Software	Pupil Capture, Pupil Player (open source)
Outputs	Gaze position, fixation duration, saccade velocity, pupil diameter, blink rate

2.2 Tobii Pro Glasses 3

Type: Wearable eye tracker

Lightweight wearable eye tracker built for naturalistic research. Wide-angle scene camera and 100 Hz gaze sampling for detailed visual attention analysis.

Parameter	Specification
Gaze Rate	100 Hz
Scene Camera	1920x1080 @25 fps, wide-angle
Gaze Accuracy	0.6°
Connectivity	Wi-Fi, SD card
Weight	76 g
Software	Tobii Pro Lab, Tobii Pro Glasses Controller
Outputs	Gaze position, fixations, saccades, heat maps, areas of interest

2.3 SMI Eye Tracking Glasses

Type: Research-grade binocular eye tracker

SMI (SensoMotoric Instruments) ETG 2 Wireless model with natural-gaze headgear and full remote control via Wi-Fi. SMI was acquired by Apple in 2017, so the hardware is no longer sold, but it remains in use in many existing lab setups.

Parameter	Specification
Sampling Rate	60 Hz binocular
Scene Camera	HD, 24 fps

Tracking	Dark pupil, binocular
Design	Natural Gaze headgear
Connectivity	Wi-Fi wireless control
Software	BeGaze analysis software
Outputs	Gaze coordinates, fixations, saccades, scan paths, pupil diameter

3. Cardiac and Electrodermal Sensors

Heart rate variability (HRV) and electrodermal activity (EDA) reflect autonomic nervous system activity. Lower HRV and higher skin conductance are both linked to anxiety and stress.

3.1 Polar H10+

Type: Chest strap — heart rate, HRV, inter-beat intervals

Widely considered the gold standard for chest-strap HR monitoring. Provides ECG-accurate data with high temporal resolution, well suited for HRV analysis.

Parameter	Specification
Processor	64 MHz microprocessor
Sensor	ECG-grade electrode
Connectivity	Bluetooth 5.0, ANT+
Memory	Internal storage for 1 session
Battery	CR2025 (~400 hours)
Water Resistance	30 m
Outputs	Heart rate (bpm), R-R intervals, HRV metrics (RMSSD, SDNN)

3.2 Moofit HW401

Type: Wearable heart rate monitor

Cost-effective chest-strap HR monitor with ECG-level accuracy. Used as a secondary HR source for cross-validation with the Polar H10+.

Parameter	Specification
Processor	64 MHz microprocessor
Sensor	ECG sensor
Connectivity	Bluetooth 5.0, ANT+
Battery	CR2032 (~800 hours)
Compatibility	Wahoo, Strava, Polar Beat, and 50+ apps
Outputs	Heart rate (bpm), R-R intervals

3.3 Empatica E4 Wristband

Type: Wrist wearable — EDA, BVP, temperature, accelerometry

Medical-grade wristband integrating multiple physiological sensors. The only device in our setup that captures electrodermal activity from the wrist, giving continuous skin conductance alongside blood volume pulse and temperature.

Parameter	Specification
EDA Sensor	Galvanic skin response, 4 Hz
BVP Sensor	Photoplethysmograph (PPG), 64 Hz
Temperature	Infrared thermopile, 4 Hz

Accelerometer	3-axis MEMS, 32 Hz
Battery	~48 hrs streaming, ~60 hrs recording
Connectivity	Bluetooth Low Energy, USB
Software	E4 Connect, E4 Realtime
Outputs	EDA (µS), BVP, skin temperature, acceleration, inter-beat intervals

3.4 TEA CAPTIV T-SENS GSR

Type: Wireless galvanic skin response sensor

Lightweight wireless GSR sensor for ambulatory research. Measures skin conductance via finger electrodes with minimal movement artifact.

Parameter	Specification
Sampling Rate	32 Hz
Weight	20 g
Battery Life	8 hours continuous
Connectivity	Wireless (TEA CAPTIV system)
Electrodes	Finger-mounted Ag/AgCl
Software	TEA CAPTIV analysis suite
Outputs	Skin conductance level (SCL), skin conductance responses (SCR)

3.5 BioPac EDA Sensors

Type: Research-grade electrodermal activity measurement

BioPac EDA100C module provides high-fidelity EDA measurement, connected to the MP160 data acquisition platform for synchronized multi-channel recording.

Parameter	Specification
Module	EDA100C amplifier
Measurement	Skin conductance (constant voltage, 0.5 V)
Range	0–100 µS
Resolution	0.001 µS
Electrodes	Isotonic gel electrodes (finger/palm)
Software	AcqKnowledge
Outputs	Tonic SCL, phasic SCR, response latency, amplitude

4. Video and Motion Capture

Video cameras and motion capture provide visual recordings for facial expression analysis and body movement tracking, complementing the physiological sensors.

4.1 AXIS P1275 Camera

Type: Network surveillance camera

HD network camera with Wide Dynamic Range and Forensic Capture for clear video in challenging lighting typical of lab environments.

Parameter	Specification
Resolution	HDTV 1080p (1920x1080)
Frame Rate	Up to 60 fps
Dynamic Range	WDR — Forensic Capture
Compression	H.264, Motion JPEG
Connectivity	Ethernet (PoE)
Outputs	HD video for facial expression analysis

4.2 AXIS P1245 Camera

Type: Compact network camera

Compact, discreet network camera providing supplementary video angles. Small form factor for unobtrusive placement in experimental settings.

Parameter	Specification
Resolution	HDTV 1080p (1920x1080)
Frame Rate	Up to 30 fps
Compression	H.264, Motion JPEG
Form Factor	Compact, board-mounted
Connectivity	Ethernet (PoE)
Outputs	Supplementary video angle for behavior observation

4.3 OptiTrack Slim X13

Type: Infrared motion capture system

High-resolution IR motion capture camera that tracks reflective markers with sub-millimeter accuracy for precise body and head movement analysis.

Parameter	Specification
Resolution	1280 x 1024 (1.3 MP)
Frame Rate	240 Hz native
Latency	4.2 ms
3D Accuracy	± 0.30 mm
Dimensions	2.7 x 2.7 x 0.9 inches
Weight	0.7 lbs (0.32 kg)
Outputs	3D marker positions, head pose, body kinematics

5. Software Platforms

Two facial behavior analysis platforms extract facial action units, emotion classifications, and gaze estimates from the recorded video.

5.1 OpenFace 2.0

Type: Open-source facial behavior analysis toolkit

Developed by Tadas Baltrusaitis at CMU MultiComp Lab. Performs real-time facial landmark detection, head pose estimation, action unit recognition, and gaze estimation using convolutional neural networks. Free for research use.

Parameter	Specification
Facial Landmarks	68-point detection (CE-CLM algorithm)
Head Pose	6 DOF estimation (translation + rotation)
Action Units	AU intensity (0–5) and presence detection
Gaze Estimation	Per-eye gaze direction vectors
Performance	Real-time from webcam, no special hardware needed
License	Academic / research use
Output Format	CSV, AVI (with overlays)

5.2 Noldus FaceReader

Type: Commercial facial expression analysis software

Commercial-grade facial analysis platform using a 468-point Active Appearance Model. Achieves 99% accuracy on the ADFES benchmark and supports both real-time and post-hoc video analysis.

Parameter	Specification
Face Model	468-point Active Appearance Model
Action Units	20 FACS Action Units
Emotions	7 basic + neutral + custom expressions
Accuracy	99% on ADFES dataset
Additional	Valence, arousal, gaze direction, head orientation
Multi-Subject	Simultaneous analysis of multiple faces
Output Format	CSV, FaceReader project files

6. Sensor Comparison

6.1 Eye Tracking

Feature	Pupil Labs Core	Tobii Pro Glasses 3	SMI ETG
Sampling Rate	200 Hz (eye cam)	100 Hz	60 Hz
Type	Head-mounted	Wearable glasses	Wearable glasses
Calibration	5-point	Single-point	Multi-point
Open Source	Yes	No	No
Streaming	Yes	Yes (Wi-Fi)	Yes (Wi-Fi)
Availability	Available	Available	Discontinued
Best For	High-freq research	Naturalistic studies	Legacy setups

6.2 Cardiac and Electrodermal

Feature	Polar H10+	Moofit HW401	Empatica E4	TEA T-SENS	BioPac EDA
Modality	ECG / HR	ECG / HR	EDA+BVP+Temp	GSR	EDA
Form Factor	Chest strap	Chest strap	Wristband	Finger sensor	Finger electrodes
Wireless	BLE + ANT+	BLE + ANT+	BLE	Wireless	Wired (USB)
Sampling	ECG-grade	ECG-grade	4–64 Hz	32 Hz	High-res

Multi-Sensor	No	No	Yes (4)	No	No
Best For	HRV research	Cross-validation	Ambulatory EDA	Wireless GSR	Lab-grade EDA

6.3 Video and Motion Capture

Feature	AXIS P1275	AXIS P1245	OptiTrack X13
Type	Network camera	Compact camera	IR motion capture
Resolution	1080p	1080p	1.3 MP
Frame Rate	60 fps	30 fps	240 Hz
Key Feature	WDR-Forensic	Compact form	±0.30 mm accuracy
Connectivity	PoE Ethernet	PoE Ethernet	USB / Ethernet
Best For	Primary facial video	Secondary angle	3D body tracking

6.4 Software Platforms

Feature	OpenFace 2.0	Noldus FaceReader
License	Open-source (academic)	Commercial
Face Model	68-point CE-CLM	468-point AAM
Action Units	Intensity + presence	20 FACS AUs

Emotion Detection	No (AU-based inference)	Yes (7 basic + custom)
Gaze Estimation	Yes (per-eye vectors)	Yes
Real-Time	Yes	Yes
Multi-Subject	Yes	Yes
Best For	Research / custom pipelines	Turnkey emotion analysis

7. Experiment Protocol

The experiment follows a 5-phase, 30-minute protocol designed to capture multimodal physiological data during psychometric testing.

Phase	Duration	Description
1. Interview	10 min	Semi-structured demographic interview and informed consent
2. Sensor Setup	5 min	Fit Pupil Labs Core, Polar H10+, and Moofit HW401; calibrate all sensors
3. Baseline	~3 min	Reading task to establish resting-state physiological measurements
4. Testing	15 min	Participants complete HADS, STAI, BFI-10, and FQ on screen while all sensors record
5. Debrief	~2 min	Participant feedback; mental health resources provided if needed

Psychometric instruments administered:

HADS — Hospital Anxiety and Depression Scale

STAI — State-Trait Anxiety Inventory (STAI-S and STAI-T)

BFI-10 — Big Five Inventory (10-item short form)

FQ — Fear Questionnaire

8. Anxiety Detection Thresholds

Literature-based thresholds used to identify anxiety-related physiological responses.

Sensor	Measure	Threshold	Source
Pupil Labs Core	Fixation duration	< 250 ms	Laeng et al. (2012)
Pupil Labs Core	Saccade velocity	Extremely high	van der Lans et al. (2013)
OpenFace	Brow furrowing (AU 4)	Increased intensity	Ekman & Friesen (1978)
OpenFace	Lip tightening (AU 24)	Increased intensity	Ekman & Friesen (1978)
TEA GSR	Skin conductance response	> 0.05 µS	Boucsein (1992)
Polar H10+/Moofit	RMSSD	< 50 ms	ESC/NASPE Task Force (1996)
Polar H10+/Moofit	SDNN	< 50 ms	ESC/NASPE Task Force (1996)

9. References

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