Al-Mustaqbal University

Biomedical Engineering Department

Class: 3rd

Subject: Rehabilitation Science and Engineering.

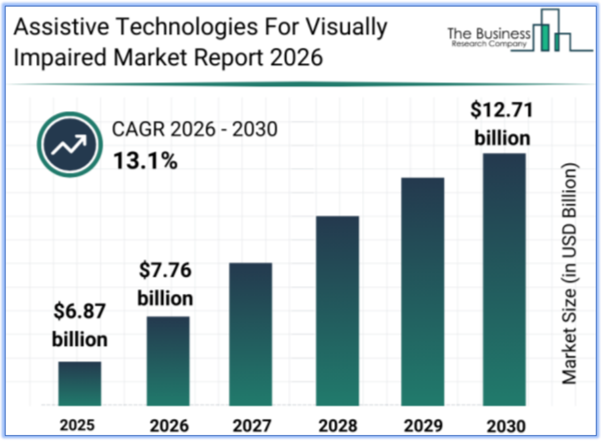
Lecturer: Mr. Mahir Rahman Al-Hajaj

2nd term – Lect. 7: Technology for Sensory Impairments (Vision and Hearing).

Email: mahir.rahman@uomus.edu.iq

Introduction to Sensory Rehabilitation Engineering.

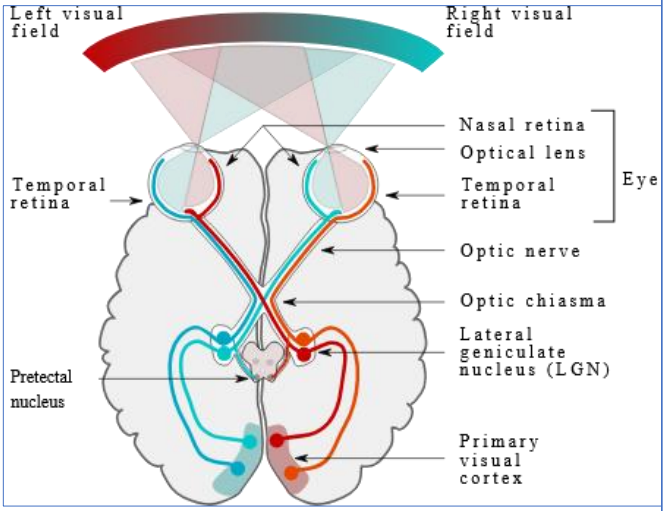
- **Engineering Sensory Pathways:** While much of rehabilitation engineering historically focused on physical mobility, sensory impairments (vision and hearing) require a different biomedical approach: capturing environmental data (photons or acoustic waves), processing it, and delivering it to a damaged biological sensor.
- **Demographics:** Visual impairment affects up to 19.1 million US adults, while hearing loss affects approximately 37.5 million American adults.



Assistive technologies for visually impaired global market report.

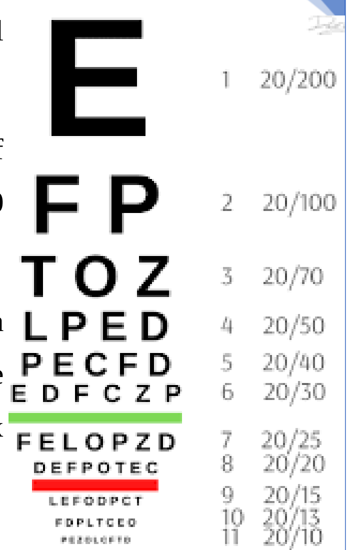
Introduction to Sensory Rehabilitation Engineering.

- **Core Disciplines:** Designing sensory aids requires an interdisciplinary mastery of Digital Signal Processing (DSP), optics, electromagnetics, and neural interfacing.
- **The Transduction Goal:** Our engineering objective is sensory substitution (e.g., routing visual data to tactile or auditory pathways) or sensory augmentation (e.g., digitally compressing audio to fit a damaged cochlea's dynamic range).



Visual Pathophysiology & Mathematical Modeling of Acuity.

- **Defining the Deficit:** "Legal blindness" in the US is defined as a central visual acuity of 20/200 or worse, or a visual field of less than 20 degrees.
- **Mathematical Example (Magnification Needs):** Acuity is a measure of spatial resolution. If a patient has 20/200 acuity, it means they see at 20 feet what a healthy eye sees at 200 feet.
- **Engineering Calculation:** To resolve the same spatial frequencies as a normal eye, the required optical magnification (M) is roughly the denominator divided by the numerator ($M=200/20=10\times$). Thus, a 10x optical or digital zoom is required to normalize their spatial resolution.



Visual Pathophysiology & Mathematical Modeling of Acuity.

- **Contrast vs. Acuity:** Clinical visual acuity measures resolution only at high contrast (black-on-white) under ideal lighting. Real-world engineering must account for low contrast sensitivity; a patient might read a 20/40 chart but fail to see a gray concrete step against a gray sidewalk.
- **Pathological Variations:** Engineering designs must adapt to the specific disease: Retinitis pigmentosa causes "tunnel vision" (requiring field-expansion optics), while Macular degeneration causes central blind spots (scotomas).

Macular degeneration

Retinitis pigmentosa causes

Optics and Electronic Magnification Systems (CCTV).

- **Optical Limitations:** While simple handheld or spectacle-mounted magnifiers provide positive lens magnification, high optical magnification drastically shrinks the user's field of view and introduces severe spherical aberrations.
- **Electronic CCTV Magnifiers:** To overcome optical physics, Closed-Circuit Television (CCTV) systems decouple the lens from the display, using digital cameras to provide variable zoom up to 60x without the same field-of-view penalties.
- **Contrast Reversal:** A critical DSP feature of CCTVs is manipulating pixel polarity. By displaying light text on a dark background, the system drastically reduces overall photon emission. This minimizes photon scatter inside eyes afflicted with cataracts, eliminating the "glare" that washes out retinal contrast.

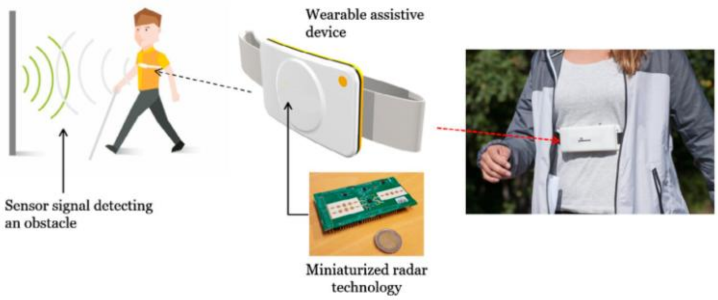
Sensory Substitution and Spatial ETAs.

- **Electronic Travel Aids (ETAs):** To assist blind pedestrians, engineers design obstacle detectors using ultrasonic or infrared signals.
- Example (Ultrasonic Time-of-Flight): An ETA emits a 40 kHz ultrasonic pulse. If the echo returns in 0.01 seconds, how far is the obstacle?
- Solution: Distance $d = (v \cdot t)/2$, where v is the speed of sound (~343 m/s).
- $d=(343\times0.01)/2=1.715$ meters.
- The microcontroller then transduces this calculated distance into proportional haptic vibration intensity or audible pitch.

Sensory Substitution and Spatial ETAs.

- **Tactile Graphics:** When visual data must be rendered physically, engineers use active tactile arrays (e.g., 32x48 dot matrices driven by piezoelectric or solenoid actuators) to dynamically raise and lower pins.
- **Sonification:** To make data accessible, software like SKDATA Tools maps 2D graphical spaces into acoustic space—mapping the Y-axis amplitude to audio frequency (pitch) and the X-axis to time.

Sensory Substitution and Spatial ETAs..



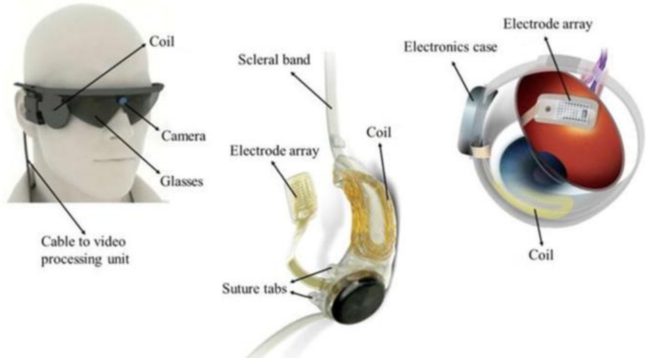
Computer Vision and AI for the Blind (Recent Update).

- **The "Remote Sighted Guide" Evolution:** Historically, apps like "Be My Eyes" connected blind users to remote human volunteers via live smartphone video to identify objects or read signs. Automated versions like "Tap Tap See" attempted early computer vision recognition.
- **Recent Update (Vision-Language Models):** In the last two years, the integration of Large Multimodal Models (like GPT-4V) has revolutionized this space. Instead of simple object detection ("cup" or "chair"), the AI can parse complex visual scenes, read poorly lit handwriting, and answer iterative, context-aware questions about the user's environment in real-time.
- **Engineering Impact:** This shifts the assistive paradigm from heavily instrumented environments (e.g., installing expensive Bluetooth beacons or Talking Signs) to "smart" edge-computing devices that rely entirely on egocentric camera feeds and cloud AI.

be my eyes

Direct Neural Stimulation: Retinal Prostheses.

- **The Bionic Eye Principle:** For diseases that cause outer retinal degeneration (such as Retinitis Pigmentosa), projects aim to restore vision using retinal or cortical implants.
- **System Architecture:** Systems like the FDA-approved Argus II use a head-mounted camera, a DSP to extract high-contrast edges, a telemetry coil to wirelessly transmit data, and an epiretinal microelectrode array to inject biphasic current pulses into surviving inner retinal ganglion cells.

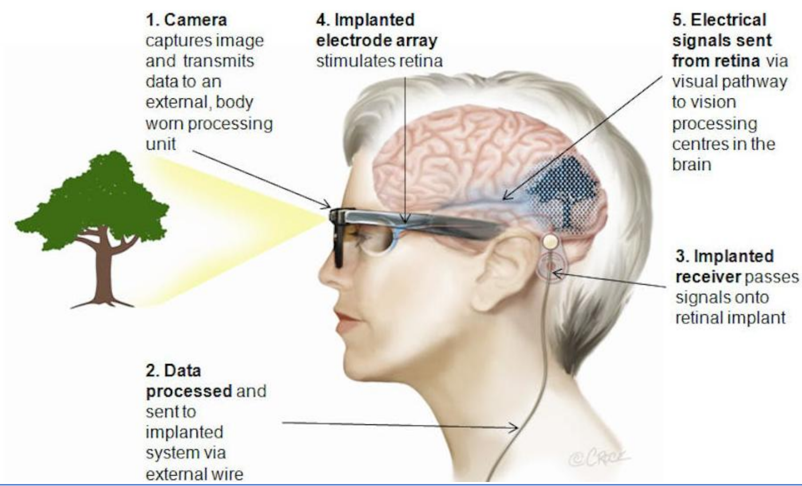


Direct Neural Stimulation: Retinal Prostheses.

The bionic eye - how it works

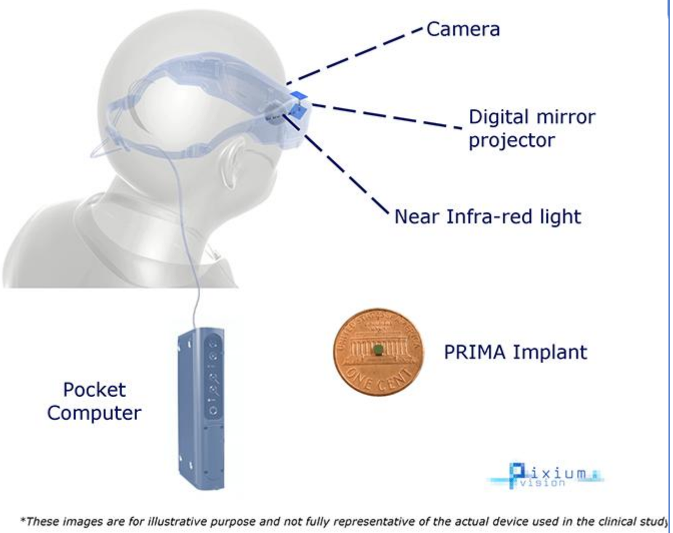
First prototype: Wide-view neurostimulator

BIONICVISION AUSTRALIA



Direct Neural Stimulation: Retinal Prostheses.

- **Recent Update (Photovoltaic Subretinal Implants):** The latest generation of prostheses (e.g., the PRIMA system) eliminates the wired epiretinal array. It uses a wireless, subretinal photovoltaic chip. Near-infrared light projected from AR glasses powers thousands of independent micro-photodiodes simultaneously, vastly increasing the pixel density and spatial resolution over older 60-electrode arrays.



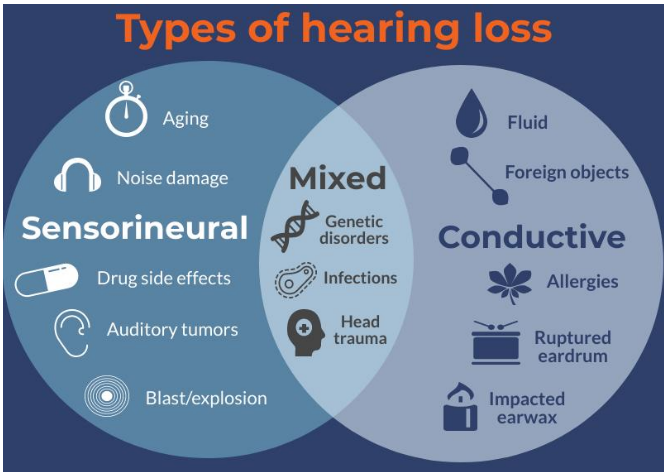
PRIMA Bionic Vision System

Direct Neural Stimulation: Retinal Prostheses.

Electronic eye implant allows legally blind to see again.

Hearing Loss Pathophysiology (Conductive vs. SNHL).

- **Conductive Hearing Loss:** Results from attenuated sound transmission through the outer/middle ear (e.g., fluid, ossicle fusion). Because it only attenuates amplitude without altering dynamic range, linear acoustic amplification is a highly effective engineering treatment.
- **Sensorineural Hearing Loss (SNHL):** Caused by damage to cochlear hair cells or the auditory nerve.

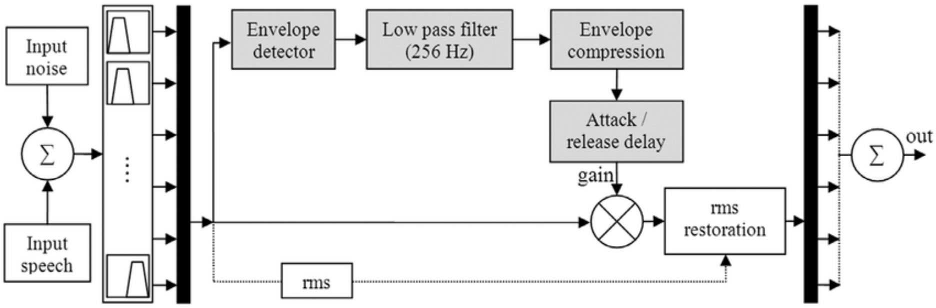


Hearing Loss Pathophysiology (Conductive vs. SNHL).

- **The SNHL Engineering Challenge:** SNHL not only raises the hearing threshold (making quiet sounds inaudible) but heavily reduces the dynamic range.
- **Biological Amplification Loss:** The loss of outer hair cells destroys the cochlea's active biological amplifier. Consequently, low-level sounds are lost, while high-level sounds are perceived at normal or even painful volumes.
- Furthermore, neural temporal resolution is degraded, destroying speech intelligibility in background noise.

Mathematical Modeling of SNHL: WDRC.

- **The Danger of Linear Gain:** If we use simple linear amplification for SNHL to make low-level sounds audible, high-level sounds will become painfully loud, risking further acoustic trauma.
- **Wide Dynamic Range Compression (WDRC):** The DSP solution is amplitude compression, applying high gain to soft sounds and low/zero gain to loud sounds.
- Because SNHL is frequency-dependent (usually worse at high frequencies), multiband compression splits the audio into contiguous frequency bands and applies compression independently.



Mathematical Modeling of SNHL: WDRC.

- **Example:** A patient's normal dynamic range of 100 dB has shrunk to a residual dynamic range of just 40 dB. Calculate the compression ratio.
- **Solution:** The Compression Ratio (CR) is defined as **CR=Δinput / ΔOutput**.
- CR=100dB/40dB = 2.5.
- Therefore, the DSP must be programmed with a compression ratio of 2.5:1. For every 2.5 dB increase in environmental sound, the hearing aid only increases its output by 1 dB, safely mapping the acoustic world into the damaged cochlea.

Evolution of Hearing Aid Hardware.

- **The Pre-Electronic Era:** Ear trumpets provided 10 to 15 dB of passive acoustic gain using horn physics to match the acoustic impedance of free space to the ear canal.
- **Analog Era:** The invention of the carbon microphone (1878), the vacuum tube (1906), and the transistor (1947) allowed progressive miniaturization, shifting devices from body-worn boxes to ear-level aids. However, analog circuits hit a hard computational limit for complex signal processing.
- **The Digital Era:** In 1982, the first all-digital hearing aid was developed using a desk-mounted array processor, proving the viability of DSP. By 1996, wearable all-digital hearing aids hit the market, allowing algorithms to process audio in discrete binary samples in virtually real time (under 10-20 msec latency) to preserve audio-visual synchrony (lip-reading).

Advanced DSP: Adaptive Feedback Cancellation.

- **The Feedback Problem:** Acoustic feedback ("howling") occurs when amplified sound from the speaker leaks back into the microphone, creating a positive feedback loop.
- **The DSP Solution:** Adaptive feedback cancellation is a mathematical feat impossible in purely analog aids.
- **Mechanism:** The DSP utilizes an adaptive filter (e.g., Least Mean Squares algorithm) to continuously estimate the impulse response of the acoustic leakage path. It generates a digital replica of this feedback signal, inverts its phase by 180 degrees, and adds it back to the input.
- **Clinical Impact:** This perfectly destructively interferes with the physical feedback, allowing for high-gain, "open-fit" hearing aids that don't plug up the ear canal, increasing comfort and high-frequency bandwidth.

Advanced DSP: Adaptive Feedback Cancellation.

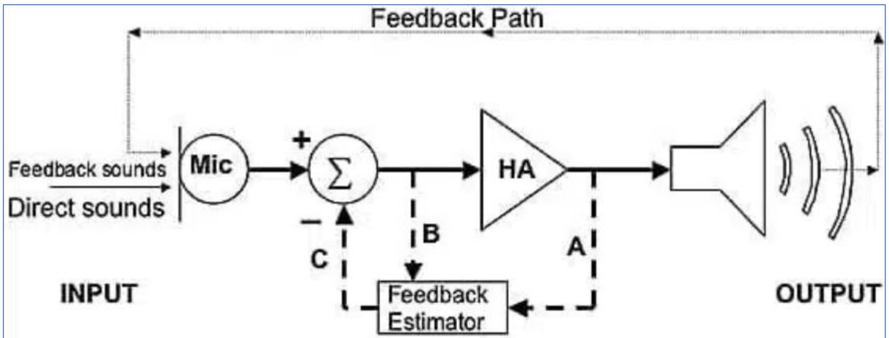


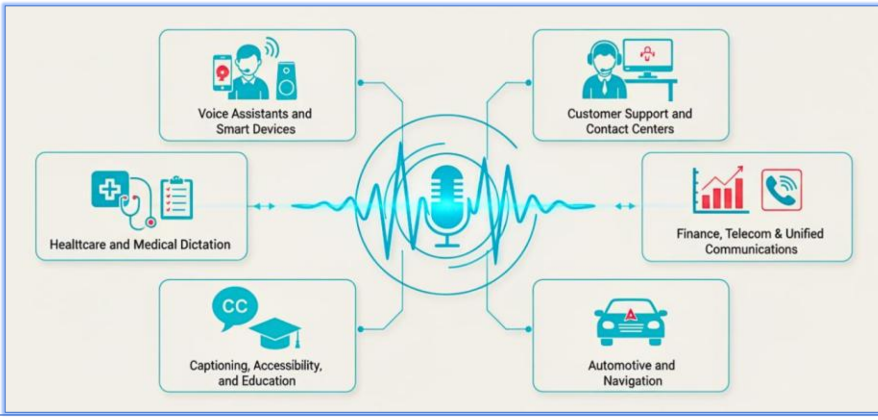
FIGURE 1. Schematic showing the mechanism of active feedback management through feedback cancellation in a single path. The "feedback estimator" correlates the sounds going into the hearing aid amplifier (B) and the sounds leaving the hearing aid amplifier (A) to identify feedback.

Advanced DSP: Adaptive Feedback Future Trajectories: The Cloud-Connected "SmartAid".

- **The Convergence:** The modern smartphone is effectively a portable computer; similarly, hearing aids are evolving into general-purpose "smartaids" linked directly to the internet.
- **Tele-audiology:** This internet connectivity allows audiologists to use automated multivariate search strategies to remotely adjust DSP parameters via cloud computing while the user is actively wearing the device in their actual noisy environment.
- **Automatic Speech Recognition (ASR):** The ultimate future noise reduction relies on the cloud. A noisy audio stream is sent to the cloud, where powerful ASR algorithms recognize the speech. The system then perfectly synthesizes the clean speech back to the user, equalized exactly to their residual audiogram.

Real-World Applications & Use Cases of Automatic Speech Recognition (ASR).

- Automatic Speech Recognition (ASR) has become a core part of today's digital ecosystem, powering everyday AI-driven speech-to-text technology across industries. From voice assistants to healthcare, automatic speech recognition systems make communication faster, safer, and more accessible.



Thank You
For Your Attention