TELEMEDICINE:
Remote Sensory Interaction with Patients for Medical Evaluation and Diagnosis

Clarence W. de Silva, Ph.D., P.Eng.
Canada Research Chair Professor of Mechatronics & Industrial Automation
Department of Mechanical Engineering
The University of British Columbia
Vancouver, Canada

e-mail: desilva@mech.ubc.ca
Web: www.mech.ubc.ca/~ial

UBC
Industrial Automation Laboratory

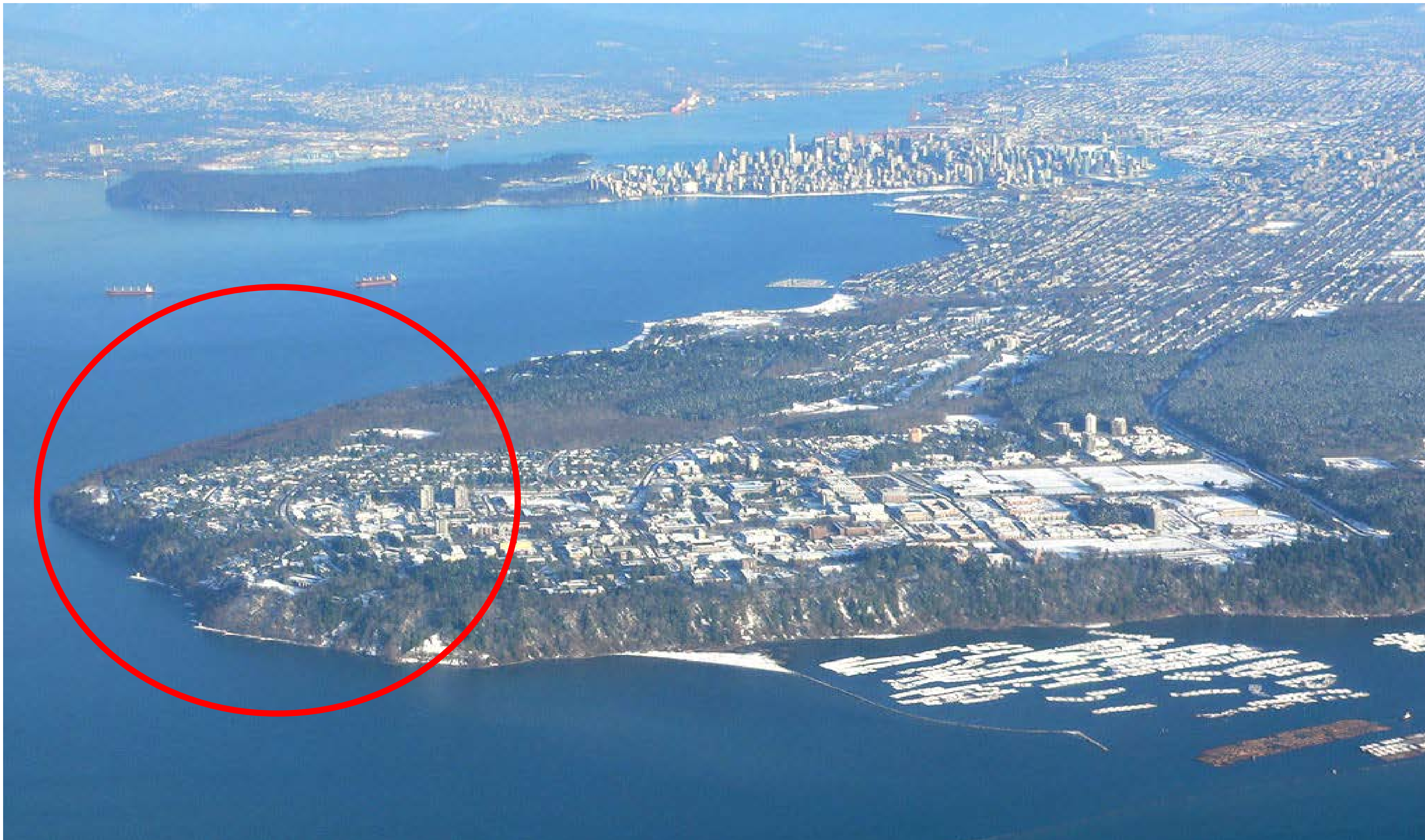
Canada and China

Canada and Vancouver






UBC Campus in Vancouver



Plan of the Presentation

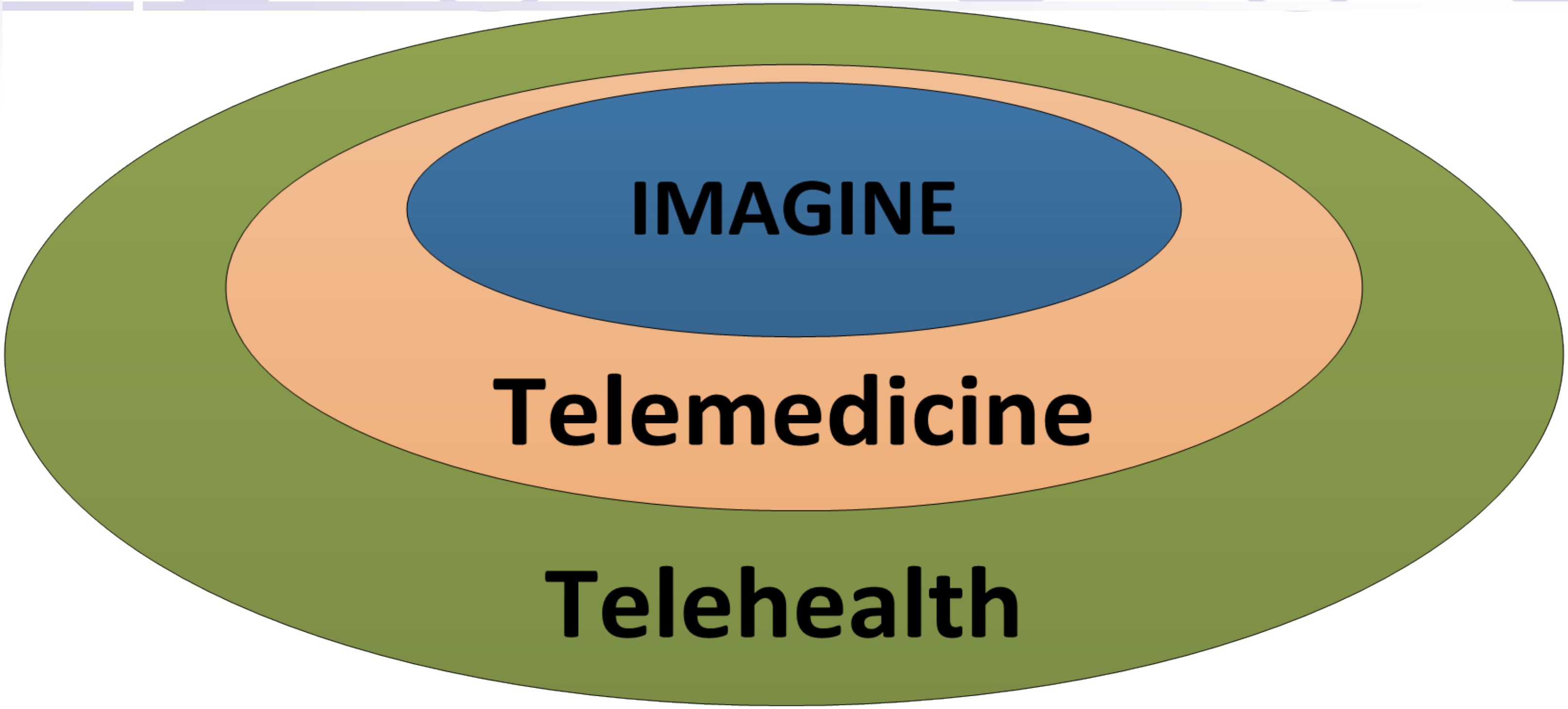
- Telehealth, Telemedicine
- Rationale for Telemedicine
- State of the Art of Telemedicine
- Technical Issues and Challenges
- Possible Solutions and Directions
- IMAGINE Project
- Technological Issues of IMAGINE

Context of IMAGINE

Positioning of IMAGINE

- **Telehealth:** Remotely monitoring and managing the health status of a person over long term (general welfare, chronic conditions, suddenly manifested serious health problems) by medical professionals, caregivers, and others
- **Telemedicine:** Provision of health services at distance by medical professionals and automated systems (on manifested serious health problems)
- **IMAGINE:** Medical diagnosis and prescription from a distance by human professionals, for rural communities in underprivileged regions

Positioning of IMAGINE



Medical Professional: Qualified to diagnose a medical condition and recommend a course of medical treatment or action
Caregiver: Directly involved with monitoring, helping, and/or treating a subject in home or local community.

UBC Industrial Automation Laboratory

Commonalities of Telehealth, Telemedicine, and IMAGINE

- Employs advanced technologies of: sensing, signal processing, information and communication
- Uses multiple sensory data on the subject
- Subject is at a remote location
- Existing communication network is used to transmit sensory data from remote location
- Some level of assessment, diagnosis, and prescription is performed
- Reduces the pressure on the existing healthcare services and infrastructure

Specificities of IMAGINE

- The subject is from an underprivileged community without local healthcare facilities
- Sensory data collection is extremely user-friendly (operations performed by the subject are very basic)
- Operations at the subject site are unsupervised
- Assessment, diagnosis, and prescription are done by human healthcare professionals

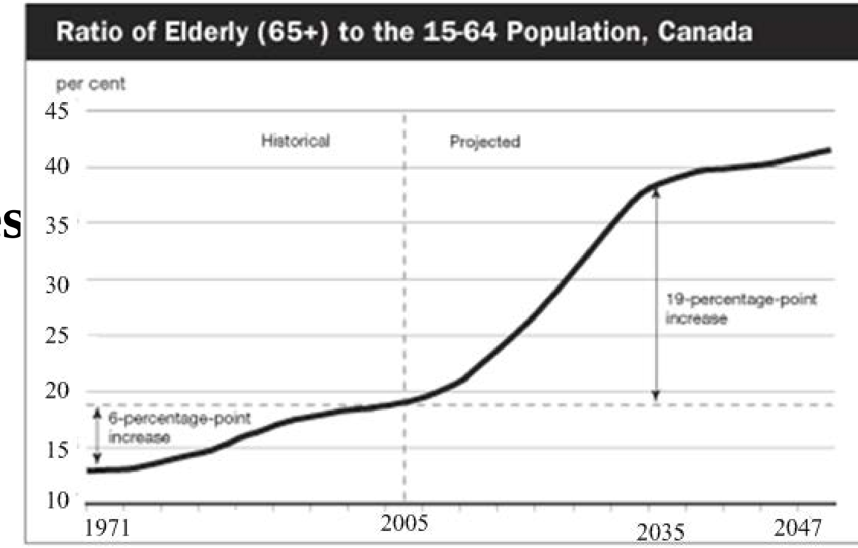
Note**: Since patient data is acquired through sensors and the assessment is done by medical professionals, "subjectivity and bias" of automated systems that depend of information provided by the patient would be absent**

Rationale for Telehealth and Telemedicine

Rationale for Telehealth/Telemedicine

➢ **Convenience, Privacy, Quality-of-Life, Speed, Economics**

- ❖ Elderly/Younger ratio in Canada will > double next 50 years
- ❖ People are happier in their own homes (privacy, independence, familiarity, convenience, etc.)
- ❖ Canadian government spends > $10 billion/year on disabled care (basic care at home by humans ~ $10,000/person/month)
- ❖ Cost of care for sick and elderly: much more
- ❖ Cost has increased by > 20% / year
- ❖ Telehealth can improve quality of life; reduce cost and pressure on existing facilities and services; is fast

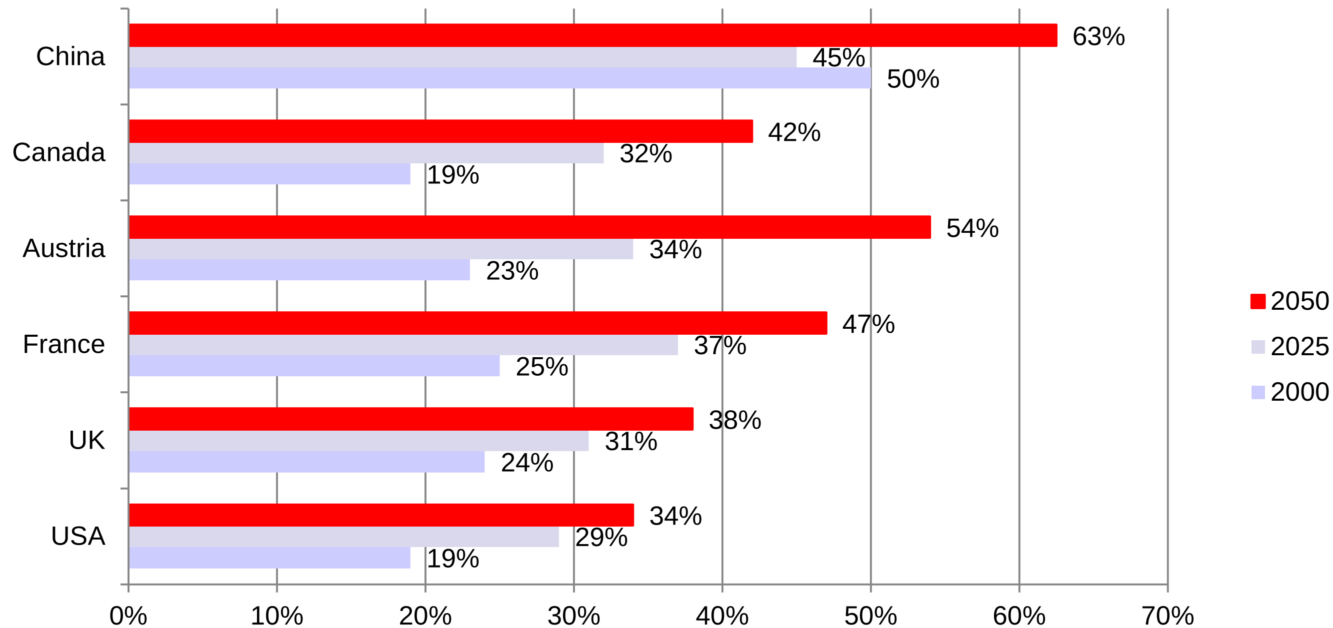


[Source: Department of Finance, Canada]

Rationale (Cont'd)

➢ **Convenience, Privacy, Quality-of-Life, Speed, Economics**

Ratio: Elderly (> 65) / Working-age (16-65)



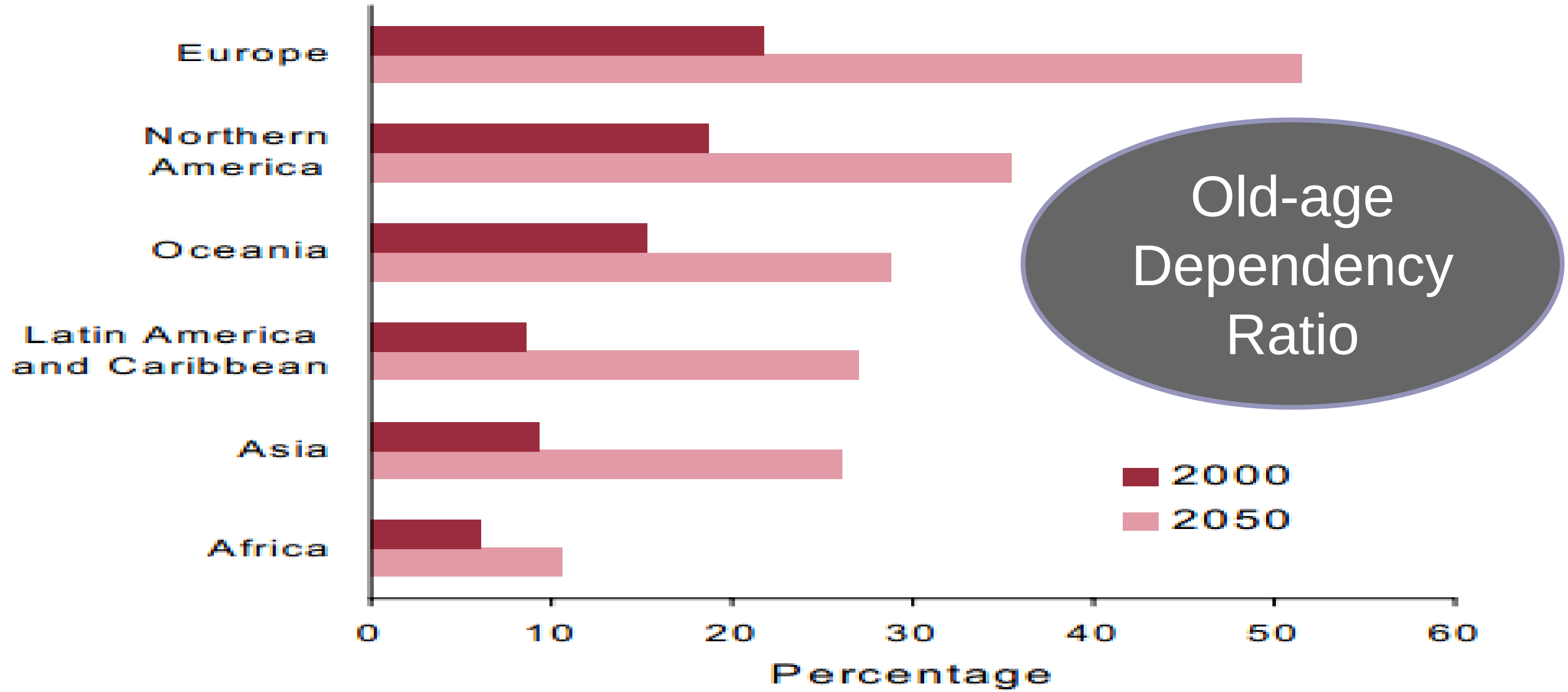
Source: UN Population Division (2009)

❖ **Situation in other regions: Comparable to Canada**

❖ **Situation will double in 50 years**

Rationale (Cont'd)

➢ Convenience, Privacy, Quality-of-Life, Speed, Economics



❖ Chart: % of elderly who rely on public (government) funds for survival

❖ Situation in other regions: Comparable to Canada

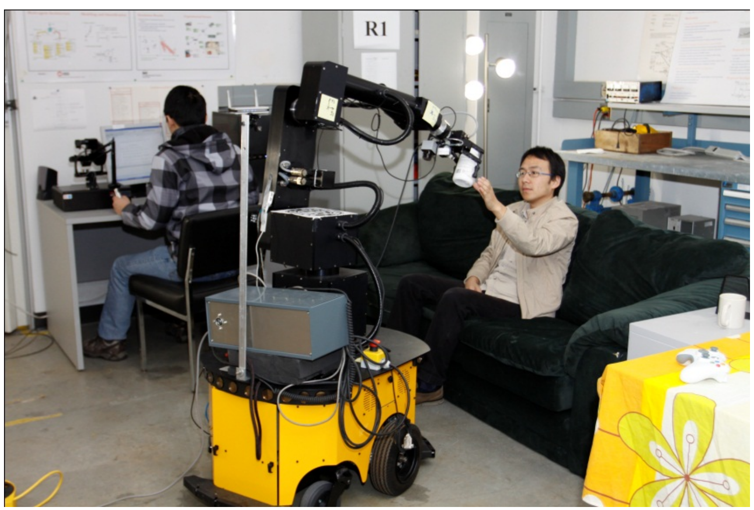
❖ Situation will double in 50 years

UBC Industrial Automation Laboratory

Summary of Rationale

- Round-the-clock, consistent/repeatable, fast, and reliable care
- No invasion of privacy (particularly important in conservative societies)
- Increased flexibility and comfort in familiar home environment
- Hospitalization may lead to morbidity and mortality
- Other family members will have increased freedom and peace of mind (pursue their normal activities: employment, education, etc.)
- Reduced cost and pressure on existing facilities and services
- Government spending will be more uniform, fair, and cost effective

Our Laboratory Environment



Equipment:

- Sensable Phantom 6DoF master (2)
- Pioneer PowerBot mobile platform (3)
- Robosoft Robu-Arm
- Barrett WAM arm
- Barrett BH8 hand with tactile sensors (2)
- Pentium 4 (5)

Telehealth and Telemedicine

Telehealth

- Involves long-term monitoring, diagnosis, intervention, and follow-up
- A caregiver may supervise and facilitate monitoring and data acquisition
- Medical professional would diagnose and advise the caregiver and the patient at remote location
- Possible self-reporting by the subject (*Note*: Partial information, inherent bias)
- Monitoring of controlled movements may be involved

Controlled Movements:

Sit-to-Stand Test: Stand and sit quickly, with arms folded (1 or 5 times)

Alternate Step Test: Stand, place foot on platform, replace it quickly back onto floor; Repeat four times with each foot

Timed Up-and-Go Test: Rise, walk 3 meters, return to chair and sit quickly

Telehealth (Cont'd)

Typical Monitored Information: Weight; Body temperature ;Blood pressure; Blood sugar; Ambulatory; Oral health; Eyesight

Ambulatory Sensors to Monitor Body Movement: Video capture; wearable ambulatory sensors/monitors or WAMs (miniature sensors or sensor systems)

Body Movement is Affected by: Physiological, anatomical, psychological, environmental, and social factors

Assessment Techniques: Physical measurement (typically under guidance); assessment by human professionals; computer-based information analysis and reduction, and automated assessment and diagnosis may be involved)

Applications: Falls detection , balance assessment, gait analysis, rehabilitation, orthotic prescription, prosthesis adjustment, orthopedic interventions

Wearable Ambulatory Sensors/Monitors (WAMs)

Accelerometer: Employs piezoelectric, piezoresistive, or variable-capacitance methods; typically placed on chest, thigh or waist along a sensitive axis; frequency range is important; low-cost; has high error when differentiating postures (standing and sitting); sensitive to device placement; separate from the gravitational acceleration (useful in determining posture)

Gyroscope: Measures angular position & velocity; uses Coriolis effect (change in angle of a spinning wheel and associated torque); Accurate in identifying body transitions between sitting and standing

Problems: Output drift over time (needs recalibration), output offsets, limited sensitivity

Inertial Measurement Unit (IMU): A combination of accelerometers and gyroscopes

Wearable Ambulatory Sensors (WAMs, Cont'd)

Magnetometer: Measures orientation of a body segment wrt earth's magnetic north; Uses earth's magnetic field and electromagnetic induction

Goniometer: Potentiometer to measure joint angle; Electrogoniometer employs strain gauges.

Inclinometer: Based on gravity; measures slope or posture

Sole Pressure Sensor: Measures reaction force on foot; Uses resistive or capacitive-based strain gauges (E.g., incorporated into socks)

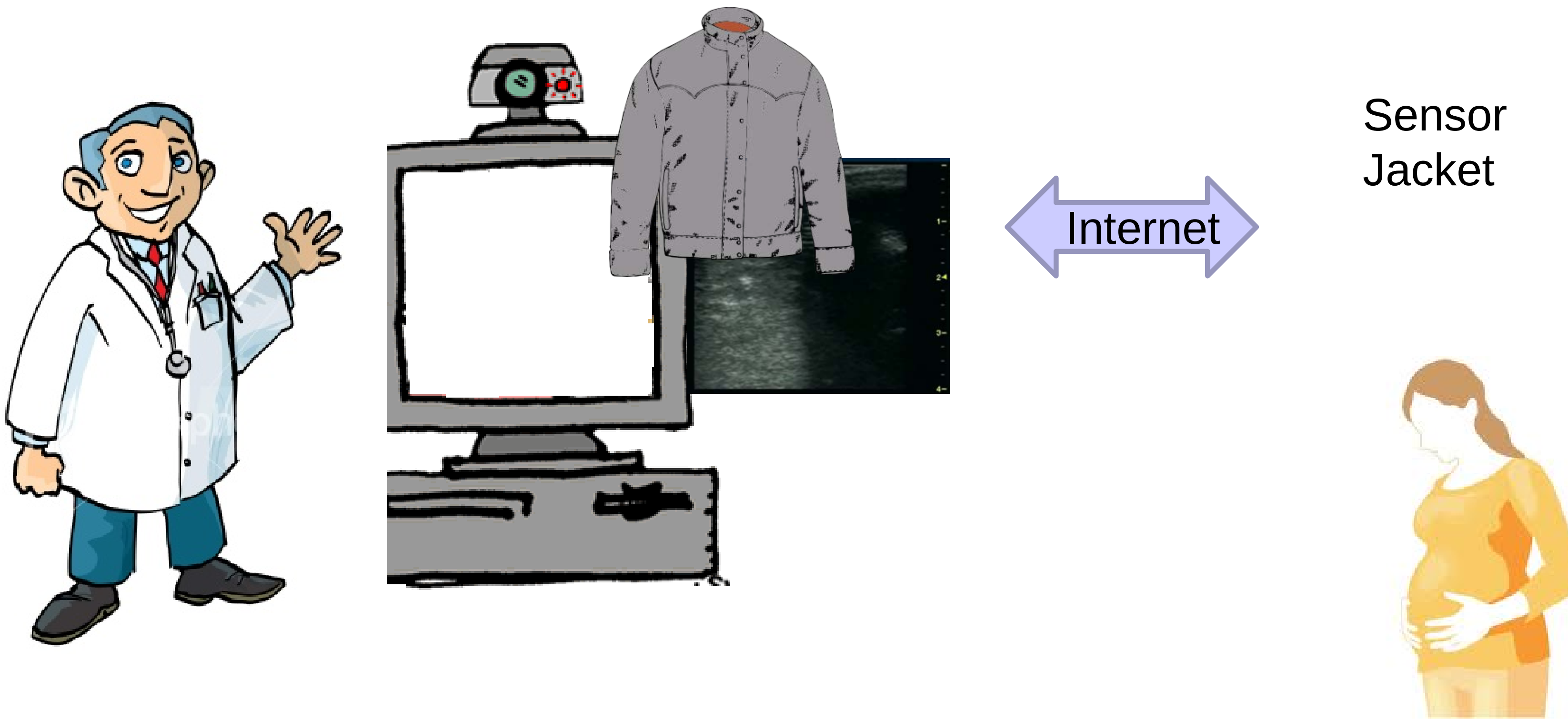
Pedometer: Step counter (Counts number of steps of performed activity); Incorporates MEMS sensors and digital processing

Actometer: Attached to body extremities; Measures mechanically produced movements; Estimates total energy expenditure (E.g., Rotor of self-winding wristwatch)

Industrial Automation Laboratory

Telemedicine (in Urban Setting: Rationale)

Telemedicine



Some Features of Telemedicine

- Typically sensing is “unsupervised” at patient site
- Data acquisition may involve remote interaction with a medical professional
- Diagnosis may be automated or manual
- Web Service-oriented Architecture: Automatic sensory data acquisition; data processing; automated diagnosis using clinical decision support system (DSS); clinical guideline-based prescription; alerting emergency service if necessary (e.g., device connects to a web service and calls ambulance)

Existing Work

Background Literature

- Salleh, 2008; An architecture and implementation of telemedicine via Internet for screening and diagnosis of heart sound and hearing
- Hsu, 2007; Web-based application for interaction between patients and doctors
- De Capua, et al., 2010; Web-service-oriented architecture for ECG measurement in Telemedicine
- Lovel and Redmond, 2010; Signal processing for Telehealth monitoring
- Xie, et al., 2010; Effect of ECG quality measures for Telehealth decision support systems
- Shany, et al., 2012; Wearable sensor systems for monitoring human movement
- Jointer, 2011; Expert systems in Telehealth

Existing Resources for Telehealth

- **California Telehealth Network (CTN), 2011:** **Collaboration of universities, medical centers, hospitals, clinics, and industry; improved access to acute, primary and preventive healthcare for under-served and rural Californians**

- **TeleMedCare Health Monitor – TMC-HM (Sydney, Australia):** **Patient selects the measurement button, lightly grasps the ECG electrodes; automatic signal acquisition, after 25 seconds recording stops automatically; sampling frequency = 500 Hz; clinical guideline-based recommendations**

UBC Industrial Automation Laboratory

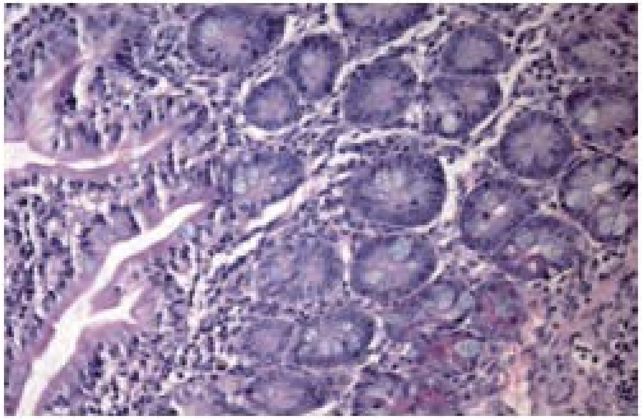
Existing Resources for Telehealth

- **American Telemedicine Association (ATA):** Certification program for providers of online medical consultations to consumers; Codes and guidelines for best practices and quality metrics
- **Online Repository:** Internet site where a visitor can browse information regarding medical issues; Intended for people who already have a diagnosed ailment
- **Cellular Telephone-based Systems (e.g., Guideview):** User runs applet on smartphone; It leads through a series of steps while asking questions; Supported by visual images etc.; Emergency personnel are dispatched to the cell phone's GPS coordinates; Diagnoses some conditions, with or without help of a medical professional; May provide links for further professional help

UBC Industrial Automation Laboratory

IMAGINE Project

Rationale



- Rural hospitals in underprivileged communities lack ready access to quality medical professionals and healthcare facilities
- Patients face difficulty in reaching a tertiary-care medical facility due to poor road conditions and distance
- Limited resources (specialist doctors, equipment, etc.) can be shared efficiently through telemedicine

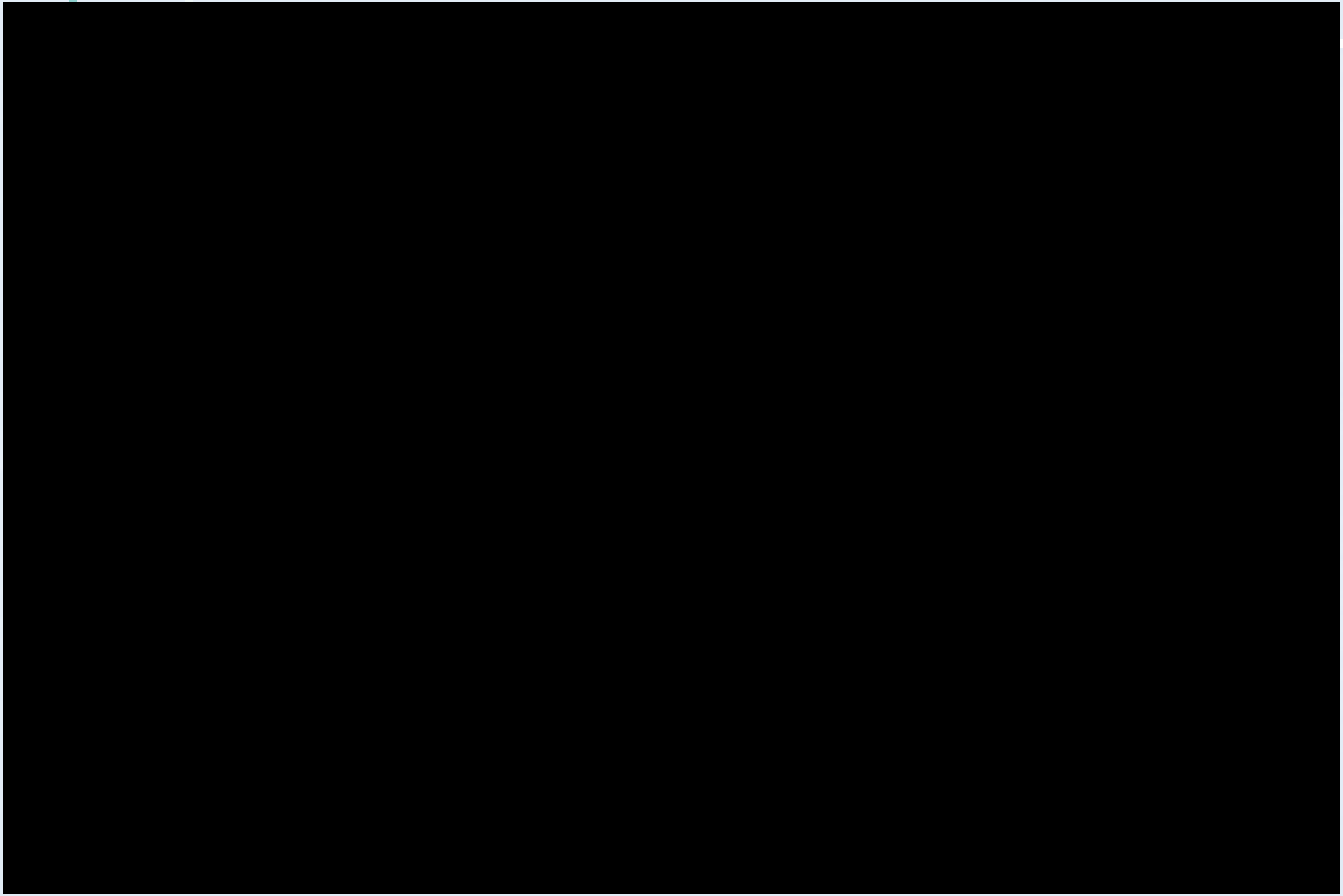
Industrial Automation Laboratory

General Approach

- Advanced sensing, signal processing, and public telecommunication are used for clinical monitoring from remote location
- Human medical professional interacts with patient remotely; does assessment, diagnosis, and prescription
- Professional may consult with other professionals and may use other resources

UBC Industrial Automation Laboratory

Telemedicine Goal



Project Collaborators

- The University of British Columbia, Canada (Industrial Automation Laboratory)
- Xiamen University, China (Prof. Maoqing Li)
- Arthur C. Clarke Institute, Sri Lanka (Prof. Lalith Gamage)

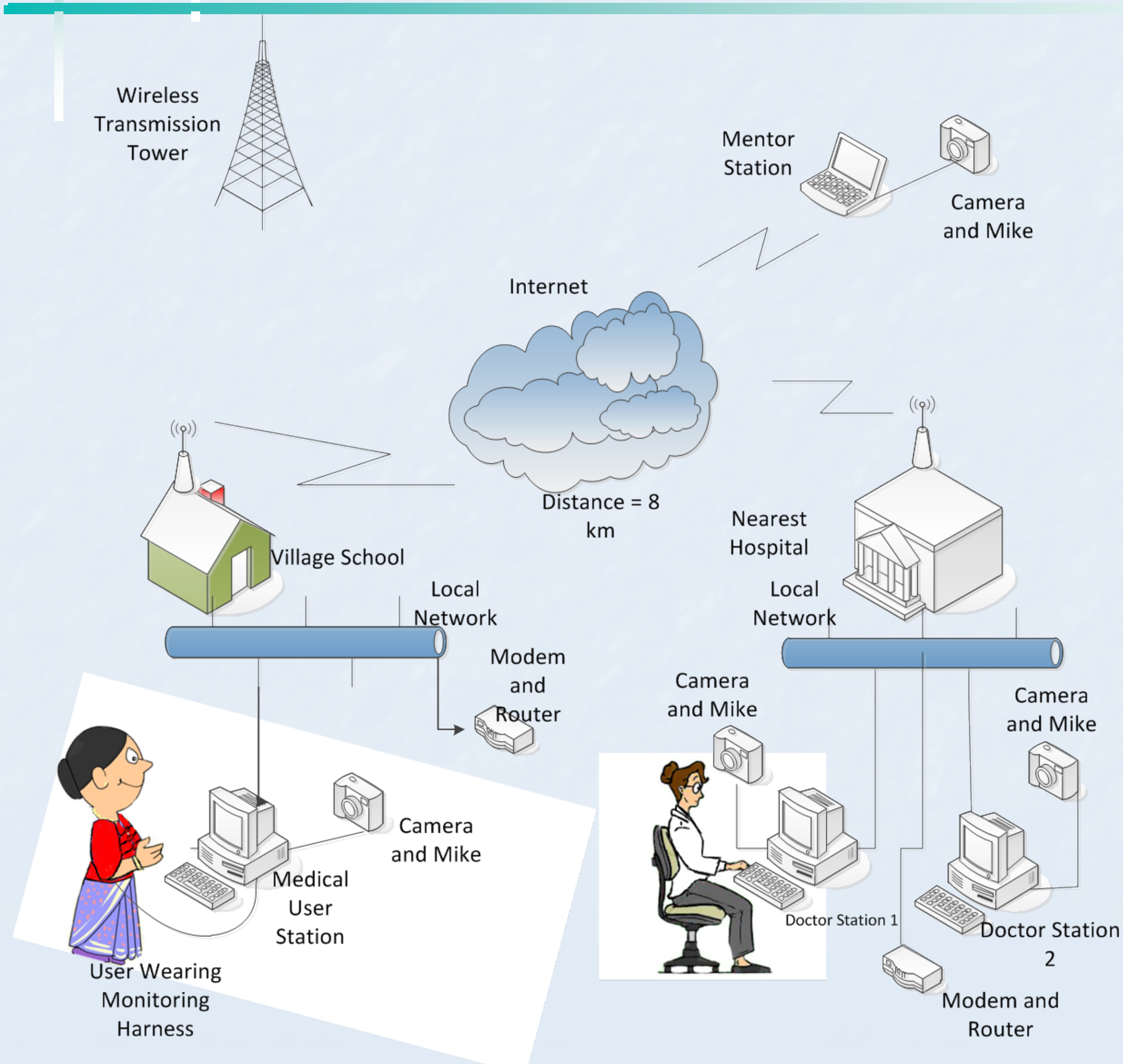
Project Overview

Objective: To provide sustainable, fast, and convenient medical consulting to people in rural areas (who do not have basic healthcare services)

Added Benefit: It will reduce hospital backlog and pressure on healthcare resources

Plan: Develop a jacket with embedded sensors to monitor vital signs (temperature, heart rate, respiration rate, acoustic cues, blood pressure, ECG, blood oxygen, etc.); Live video and audio links

Project Schematic



Note: **Sensing / Monitoring; Processing; Remote interaction & Diagnosis; Prescription.**

Telemedicine Process

Monitored Data:

- Signals from embedded sensors of the jacket
- Visual cues from ear, throat, eyes, nose, etc. from a camera at monitoring station
- Voice and Live Image (live remote interaction)

Interaction:

- Data will be filtered, condensed, formatted and transmitted through Internet to remote hospital
- Physician at hospital will interact with patient in real time (may consult peers or other medical resources)
- Physician will diagnose, advice, and prescribe
- Prescription sent to patient (for printing)

UBC Industrial Automation Laboratory

Relevant Issues

- Sensor types and features (e.g., wireless multi-ECG)
- Sensor locations and configuration
- Power requirements (battery or ac with adapter)
- Sensor jacket design
- GUI (at both ends: patient and doctor)
- User friendliness, privacy, sanitation, etc.
- Hardware, signal processing (on sensor jacket, PC)
- Data Communication (jacket to PC; PC to doctor)
- Accuracy, robustness, and speed
- Cost
- Ease of cleaning, maintenance and repair

UBC Industrial Automation Laboratory

Sensors

Basic Sensors

- Medical CCD Camera
- 12-lead Digital ECG Unit
- Digital Stethoscope
- Digital Blood Pressure Monitor
- Digital Ear or Arm-pit Thermometer
- Pulse Oximeter

Patient-End Computer

Sensor Jacket

Industrial Automation Laboratory

Digital Stethoscope
(Agilent Technologies; 4.5 Vdc, 1 mA)

- Captures sounds from heart and lungs
- Signals have to be amplified before acquisition by computer
- 8 levels of sound amplification
- Active noise filtering
- Mode selection
  - Standard Diaphragm and Bell modes
  - Extended Diaphragm mode: to hear high-frequency sounds (e.g., produced by mechanical heart valve prostheses)

Digital ECG Recorder
(Fukuda Denshi, 12-Lead Digital ECG Unit, 100-240V/50-60Hz AC adapter)

- **Captures full electrocardiogram and forms a data file**
- **Built-in software to process and interpret the signals (to assist diagnosis of some heart problems by doctor)**
- **Channel (lead) selection feature (to output different processed information)**

Imaging, Blood Pressure, Temperature, and Blood Oxygen Sensing

- **Medical CCD Camera**: (**AMD Telemedicine**, 110-220 VAC, 50-60 Hz or 12 VDC)
  - With built-in illumination source
- **Digital Blood Pressure Monitor**: (**Bios Diagnostics or Omron**, 110-230 VAC adapter, PC connectivity)
  - Blood pressure and pulse rate
  - Cuff inflated by pressing a button
- **Digital Ear Thermometer:** (**Becton Dickinson and Co./Advanced Monitors Corp.**)
- **Pulse Oximeter**: (**Devon Medical Products**; fingertip or earlobe typical; forehead and chest models are available)

Note: **Blood pressure and temperature readings may be wirelessly transmitted to patient-end computer by embedding low-power miniature transceivers into the sensors.**

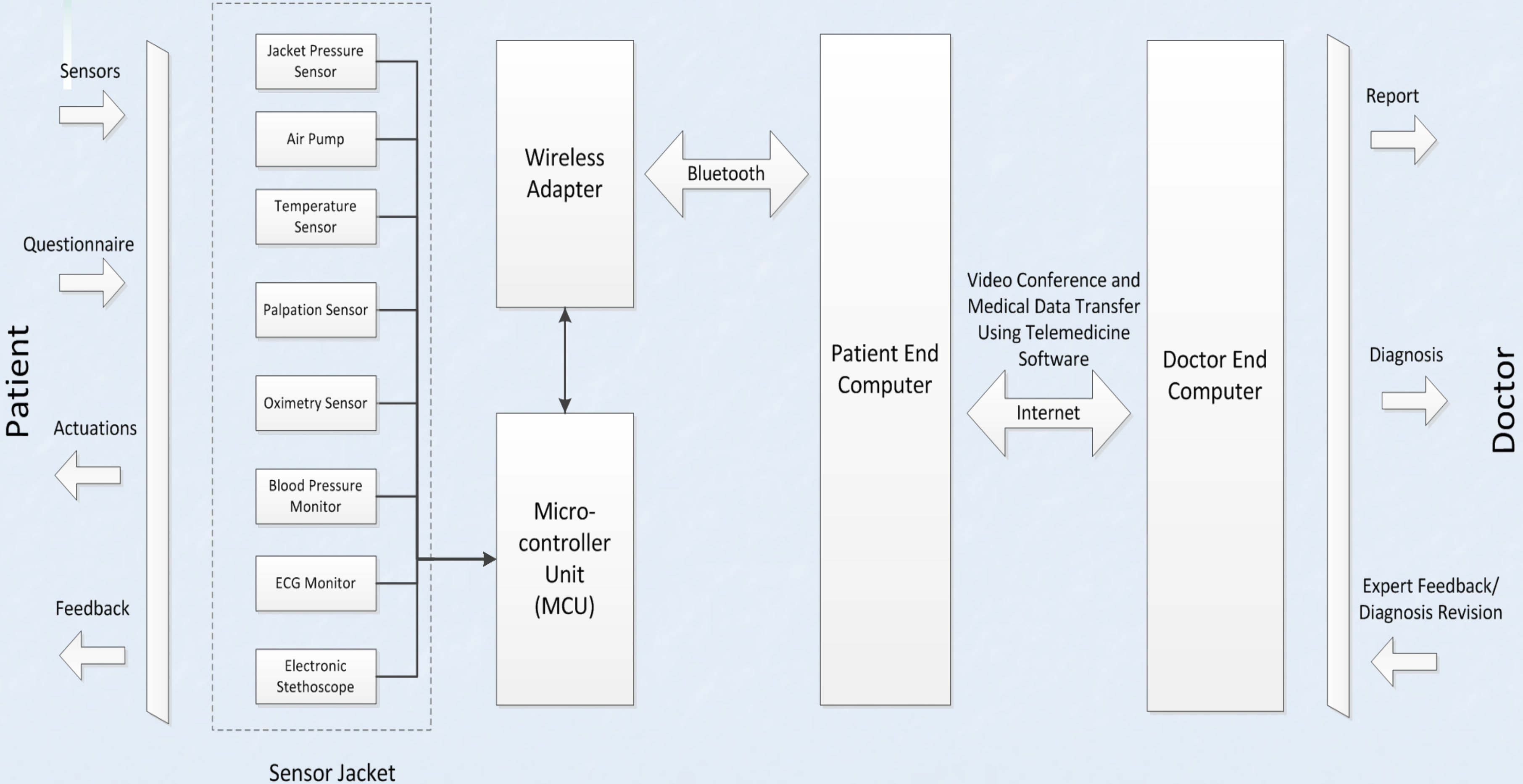
Industrial Automation Laboratory

Sensor Power Supply Capabilities

- Off-the-shelf sensors with built-in **AC adapters** (100-240 V universal, 50-60 Hz)
  - **ECG unit**
  - **Medical CCD camera**
  - **Blood pressure monitor**

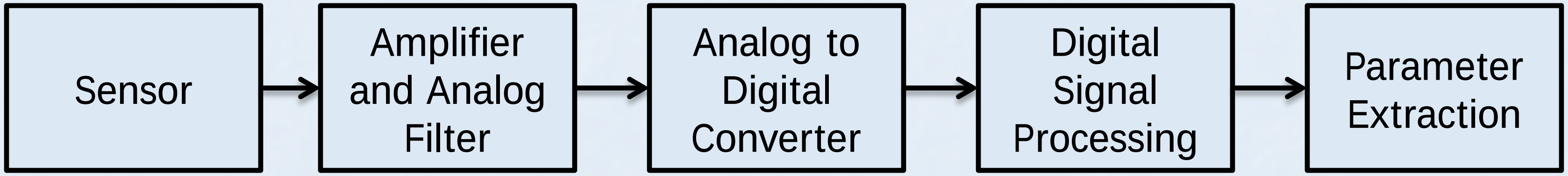
- **Stethoscope**, **thermometer**, and **pulse oximeter** are powered by **disposable batteries**

General System Overview

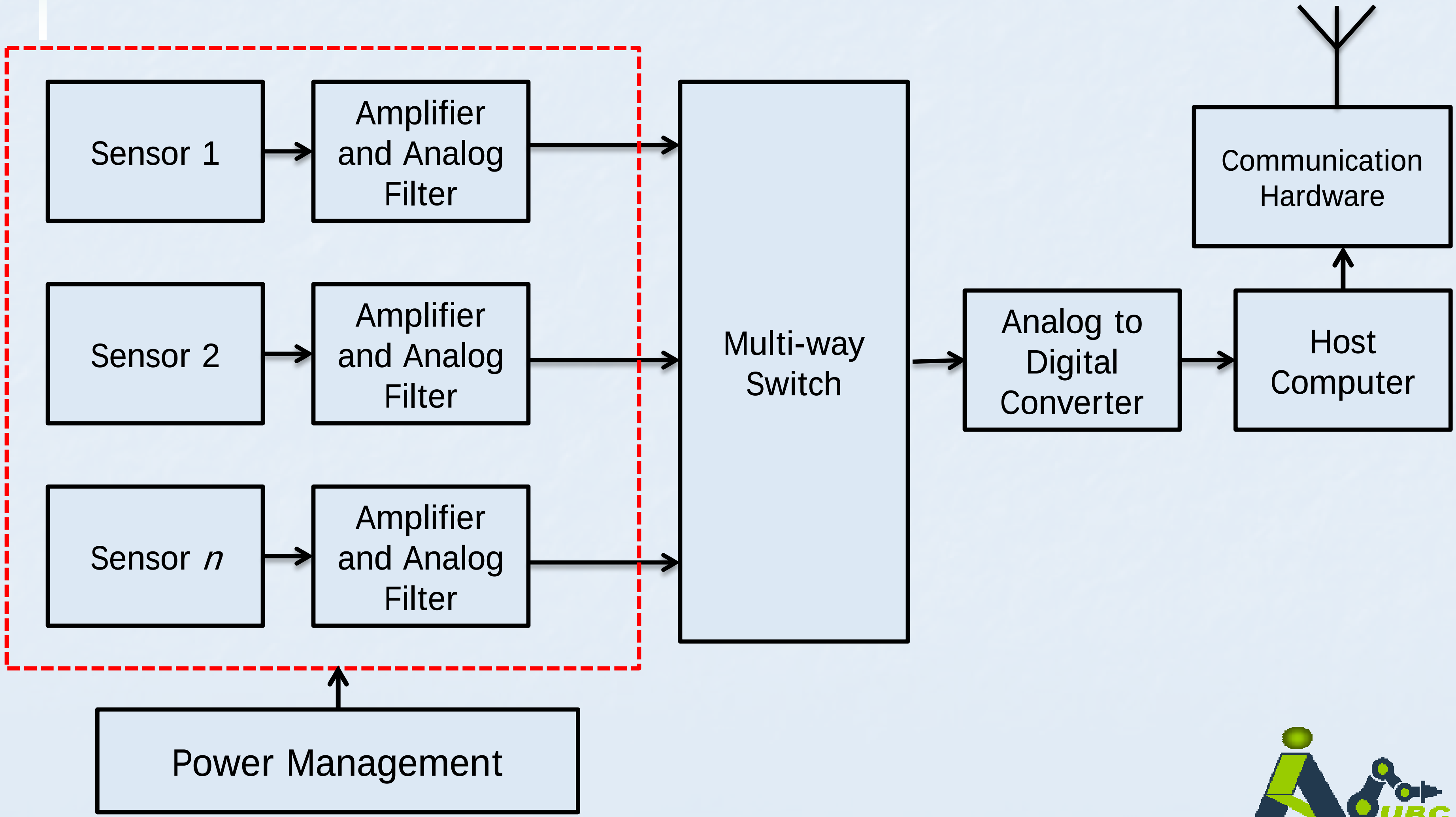


Signal Processing

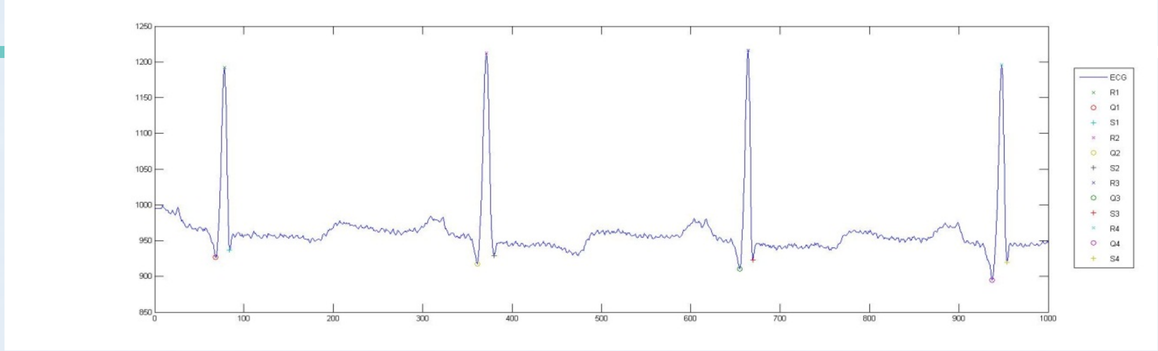
Signal Processing



Signal Acquisition



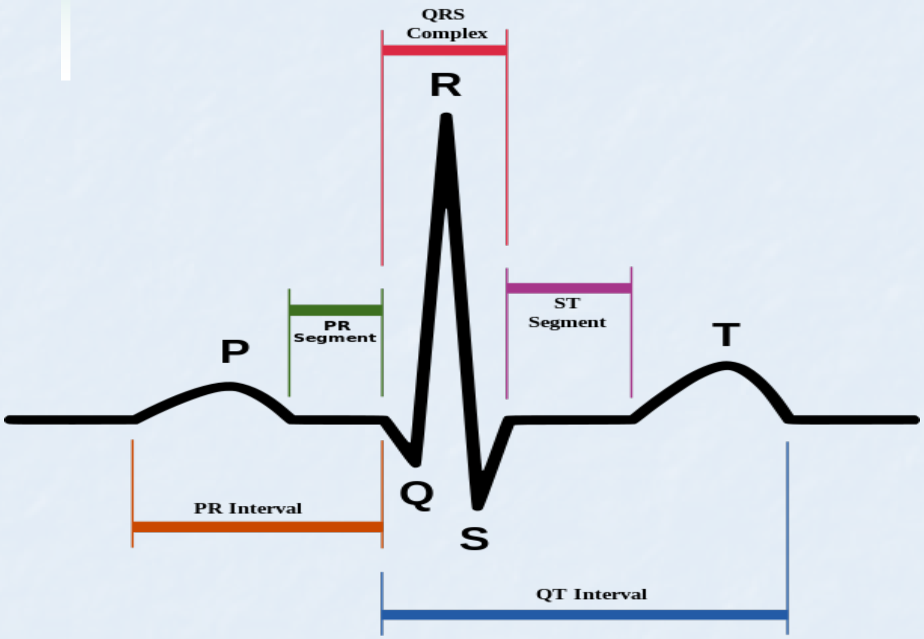
ECG Example



- **ECG signal: 0.2 to 2 mV in bandwidth 0.5 to 100 Hz**
- **Often contaminated by noise and artifacts**
- **Preprocessing is necessary (amplification and filtering)**
- **Conditioning: Amplification (a gain 7 V/V), analog filtering, signal sampling (12-bit; further filtering and amplification), digital filtering (band-stop filter in 55-65 Hz to eliminate line noise; 10th order Butterworth low-pass filter with 100Hz cutoff)**

Industrial Automation Laboratory

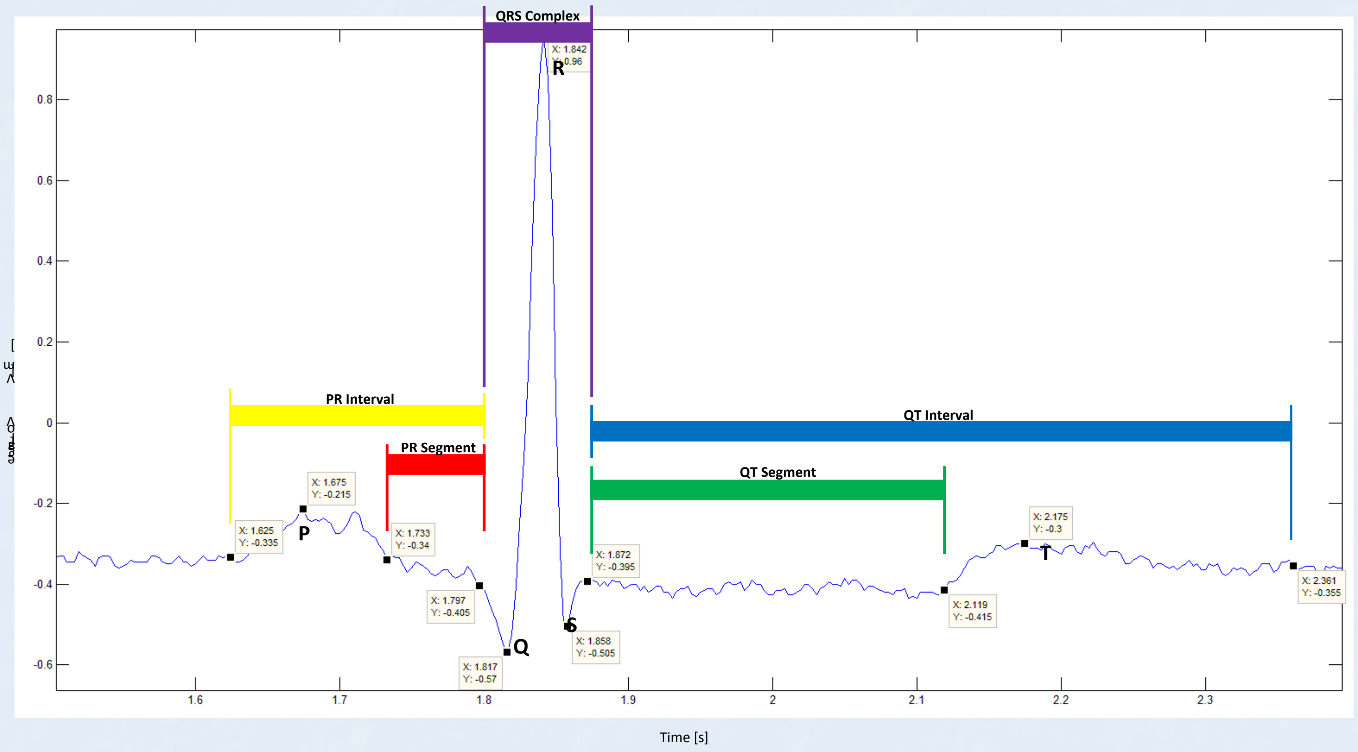
ECG Example



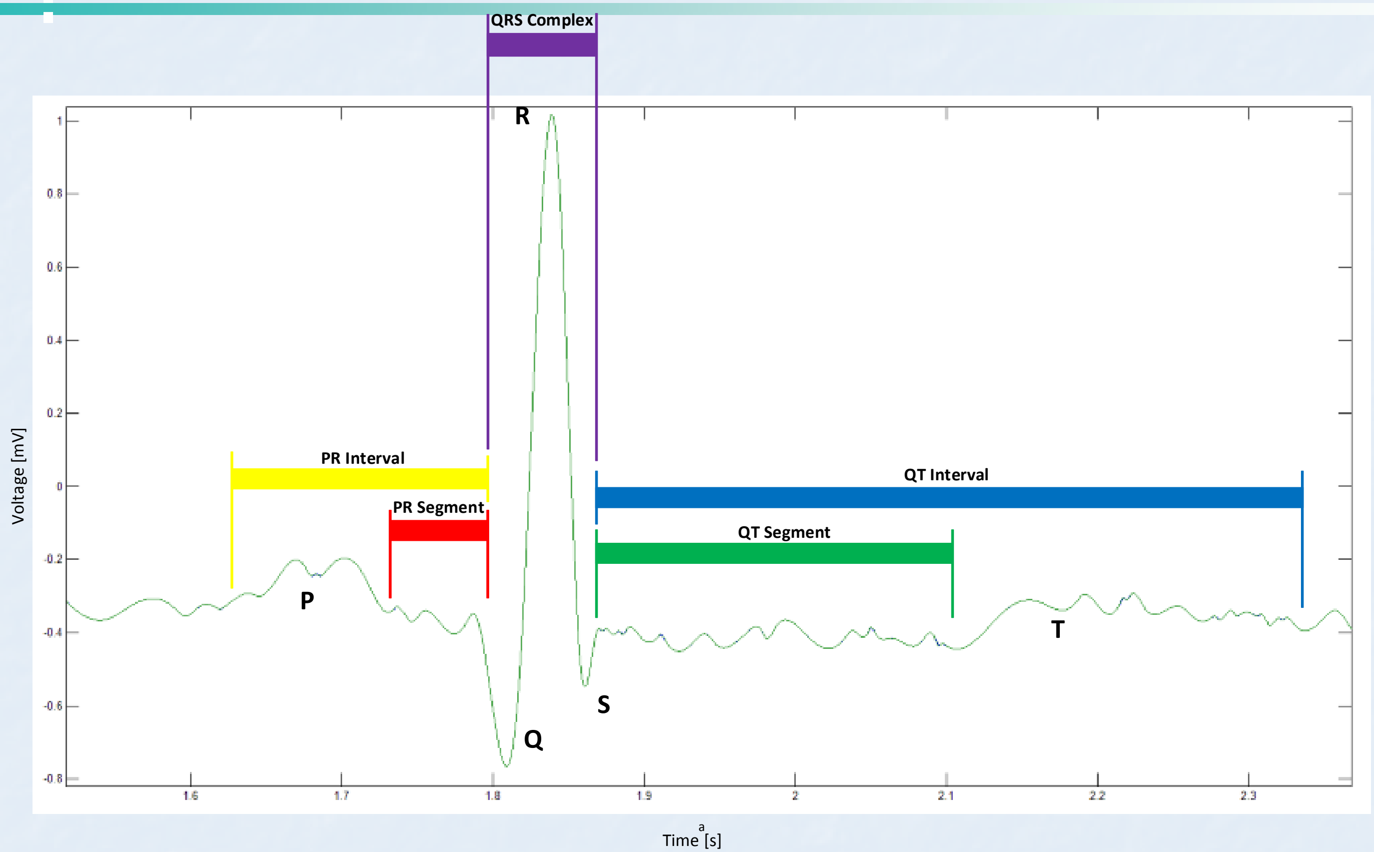
- Features such as peak and duration of QRS complex are used in diagnosis

- 40 s of record; sample rate = 1 kHz (12-bit data → 0.5 Mbits
- Average rural area network (1Mbit/s) → speed is not an issue
- Data integrity (packet loss, contamination) is an issue → Transmit PQRST (and U) attributes and
- represent on a model at doctor's site

ECG Example: Original Signal



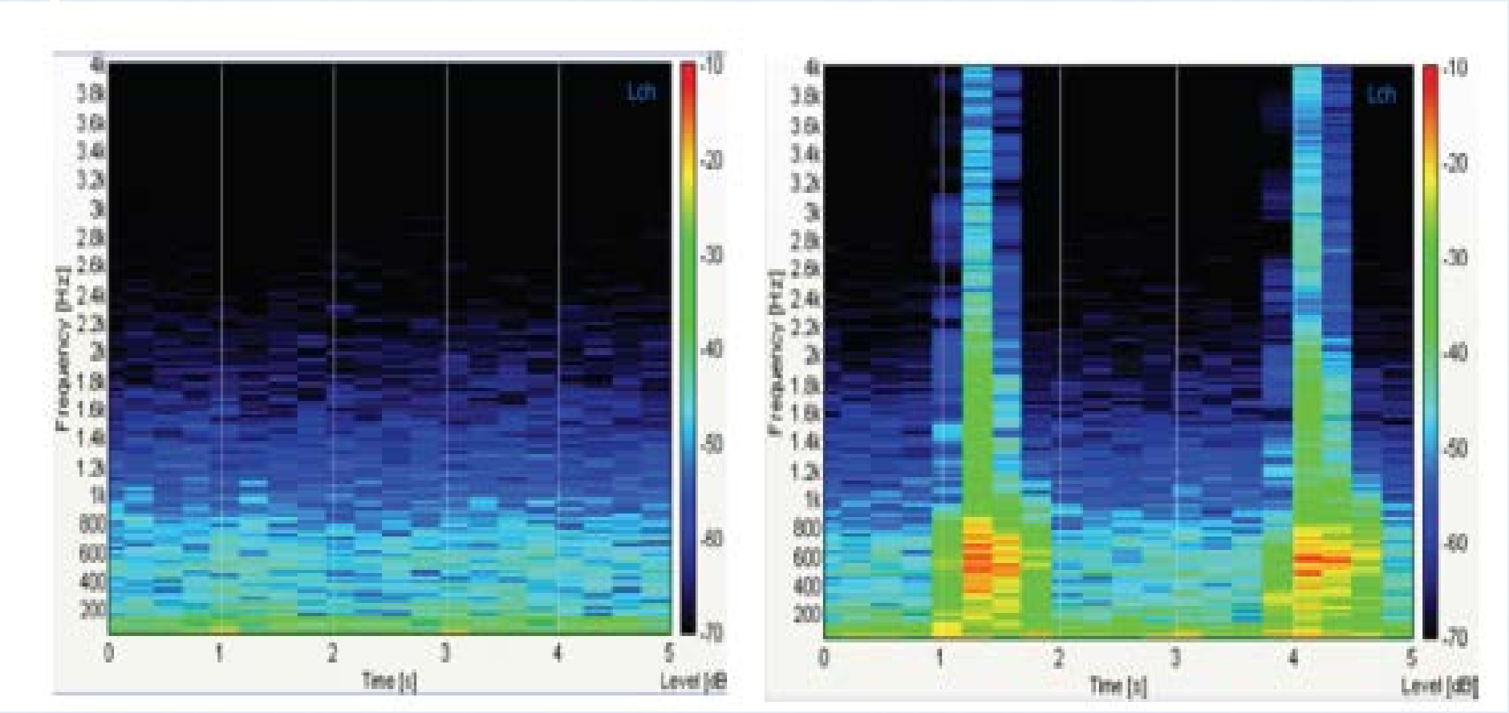
ECG Example: Reconstructed Signal



- **Peak-valley points** above a **threshold** value were transmitted
- **ECG signal was reconstructed** through curve-fitting
- **Ten-fold reduction** in transmitted data

Industrial Automation Laboratory

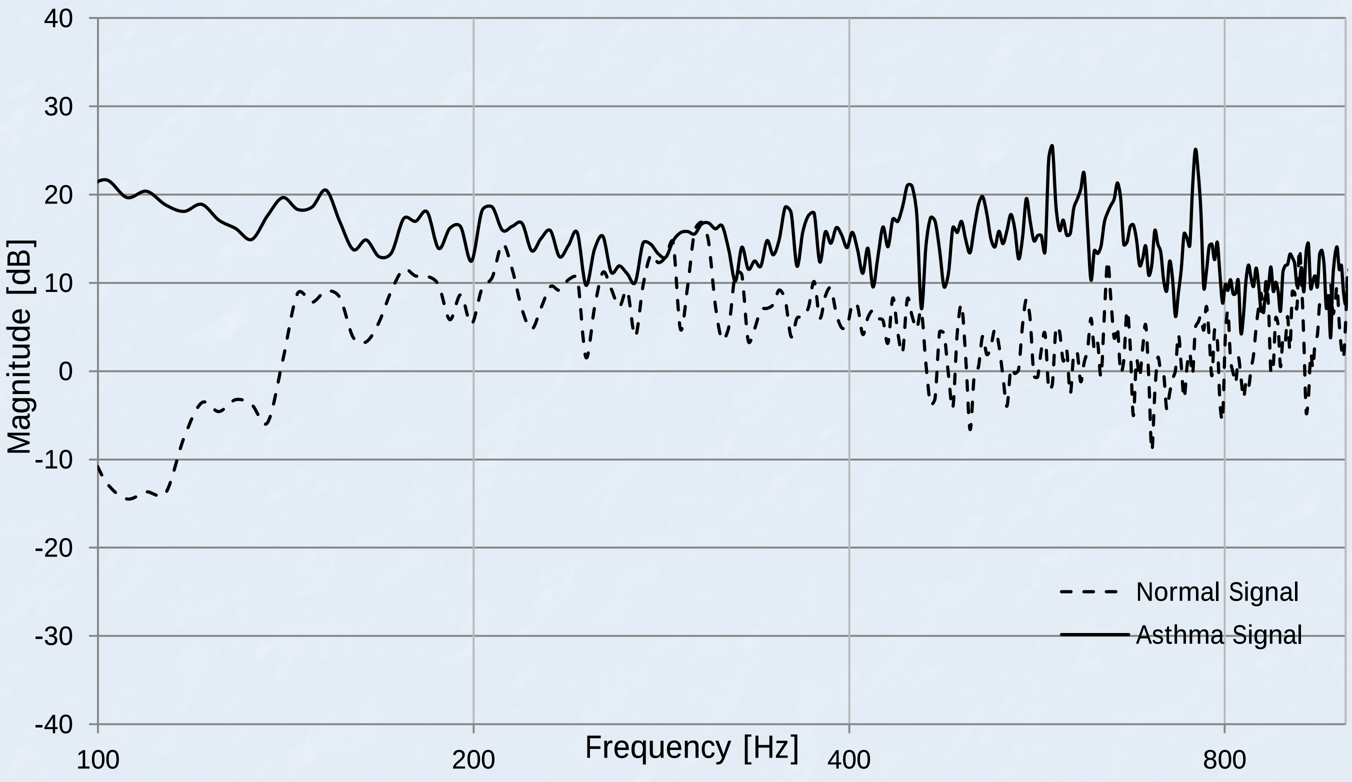
Respiratory Signal



Frequency spectra of analog stethoscope (breathing) data: Breath transmission absent (left); Breath transmission present (right).

Industrial Automation Laboratory

Respiratory Signal



Frequency spectra of analog stethoscope signals: Normal and Asthmatic

Industrial Automation Laboratory

Signal Artifact Removal

- **ECG:** Muscle tremor; low-frequency artifacts due to respiration; **Use adaptive filtering**
- **Blood Pressure (BP):** Relative movement between arm and cuff creates a rustling sound; if initial cuff pressure is not high enough the blood vessels will not be completely occluded, and estimate the systolic pressure will be inaccurate; **Compensate using microphone signals**
- **Pulse Oximetry:** Use **accelerometers** or **additional light sources**

Pulse Oximeter: Fingertip or earlobe, and probe → LEDs (red and infrared) and photo-detector on the two sides → Record light intensity due to pulsatile arterial blood flow at location → Estimates arterial oxygen level and saturation (SpO2)

UBC Industrial Automation Laboratory

Further Signal Processing

- Useful for Clinical Decision Support Systems (e.g., for Automated Diagnosis)
- Not all essential in IMAGINE (which uses human medical professionals for clinical decision making)

Approaches:

- Adaptive filtering
- Bias removal
- Data quality metric computation
- Peak detection
- Threshold analysis
- Pattern recognition and extraction
- Piecewise-linear trend detection (piecewise regression)
- Model-based parameter extraction

User Interface

Graphic User Interface (GUI)

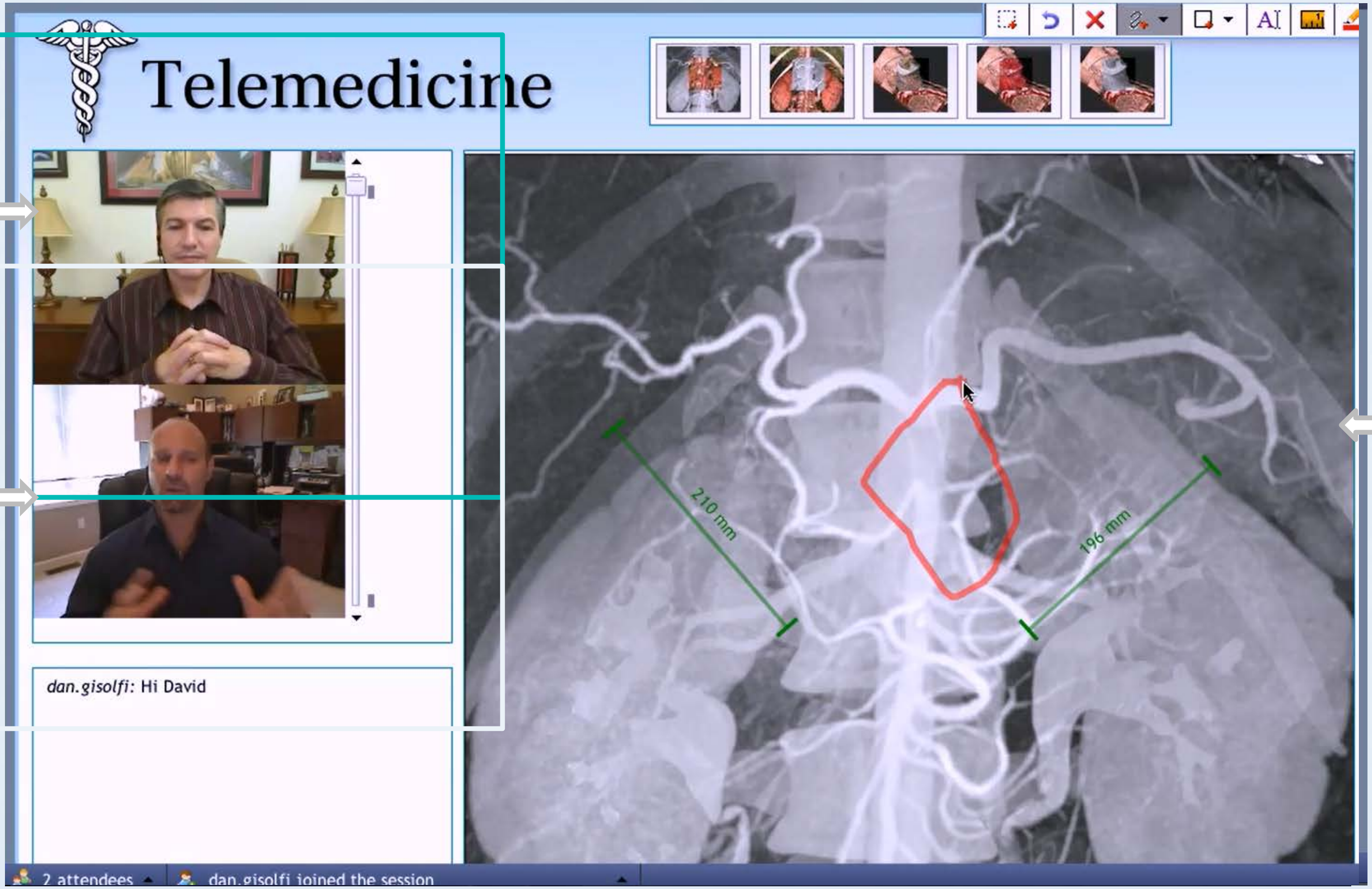
- An interactive graphic user interface (GUI)
- To assist the patient-end personnel in operation of the system and proper data acquisition
- To assist doctor in using the transmitted data and other resources in making a proper assessment and diagnosis (e.g., click on ECG button on screen → Display of human with sensor locations; Click on a sensor location → Corresponding sensor signals, patterns and key numerical values)
- Necessary software development (e.g., in MATLAB)

Industrial Automation Laboratory

Telemedicine System GUI

Patient

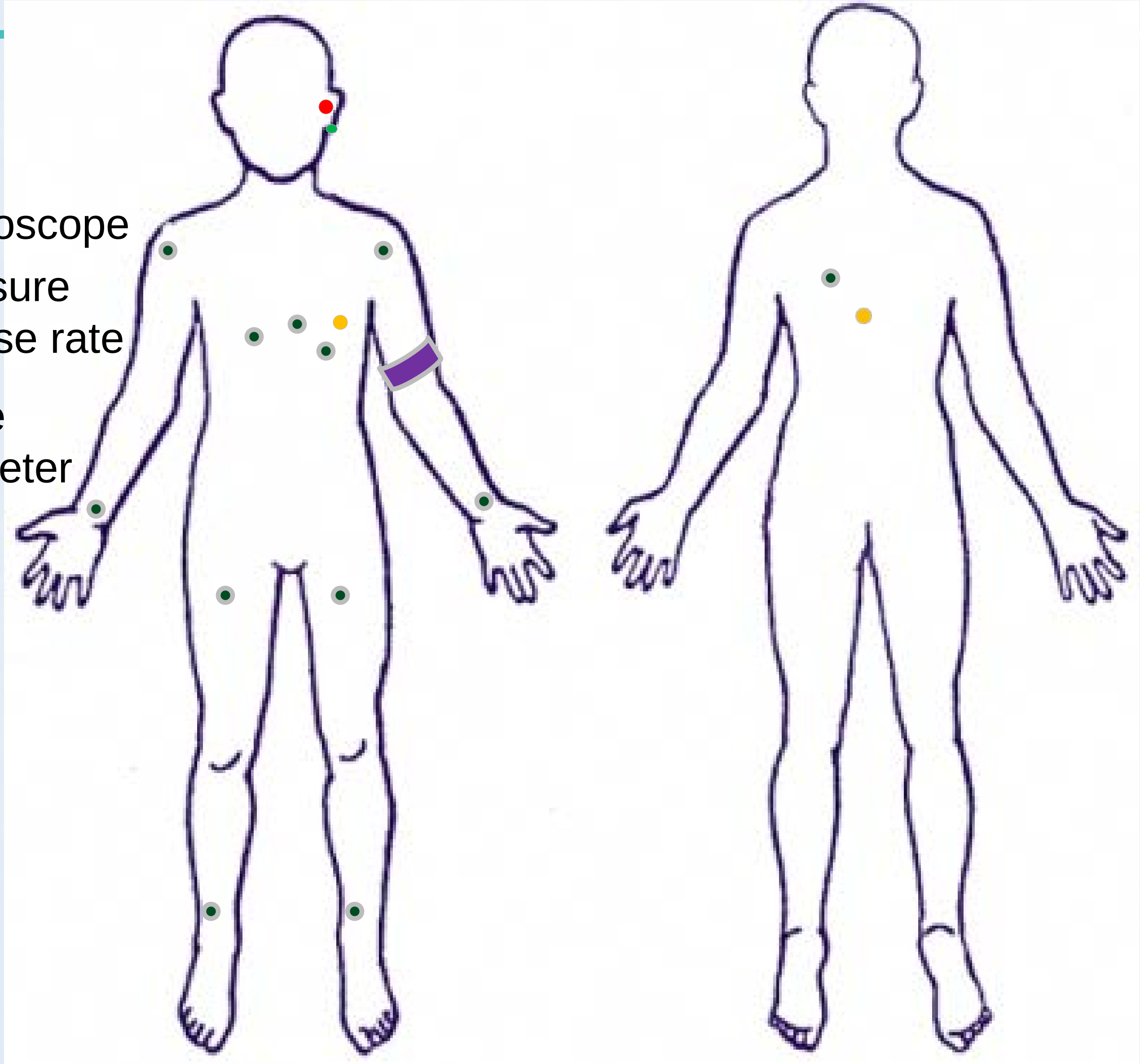
Doctor



Medical Image

Doctor's Screen

- ECG
- Temp
- Stethoscope
- Pressure + pulse rate
- Pulse Oximeter



Data Communication

Data Communication Issues

- Transmission of sensor data to patient-end computer (e.g., Embedded wireless transceivers for transmitting sensor data)
- Available Internet services, bandwidth, network traffic, reliability, etc.
- Communication protocol

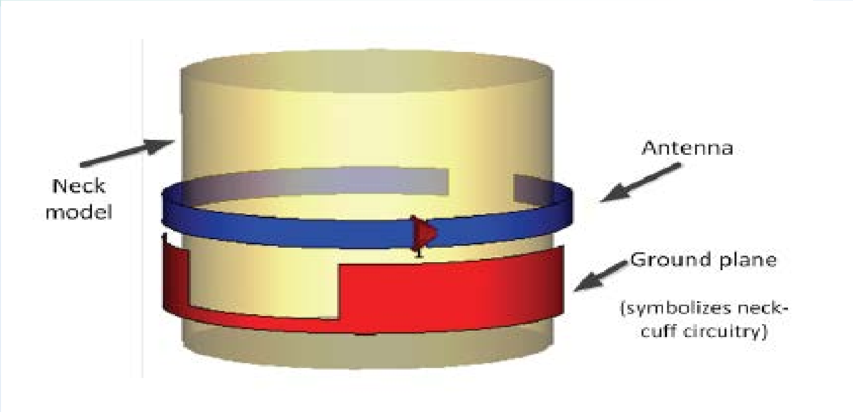
Industrial Automation Laboratory

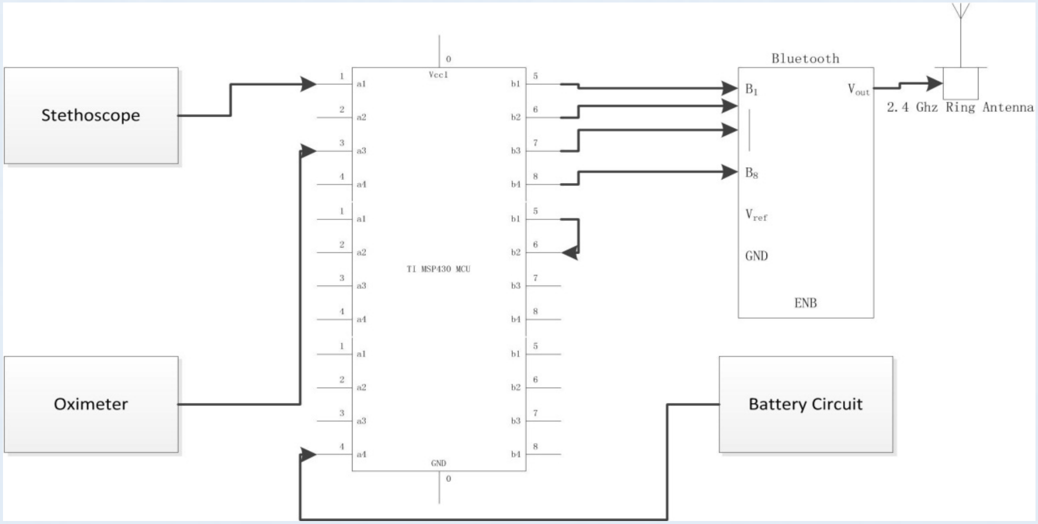
Example: Neckband Sensor Module

Sensors: Oximeter, Stethescope

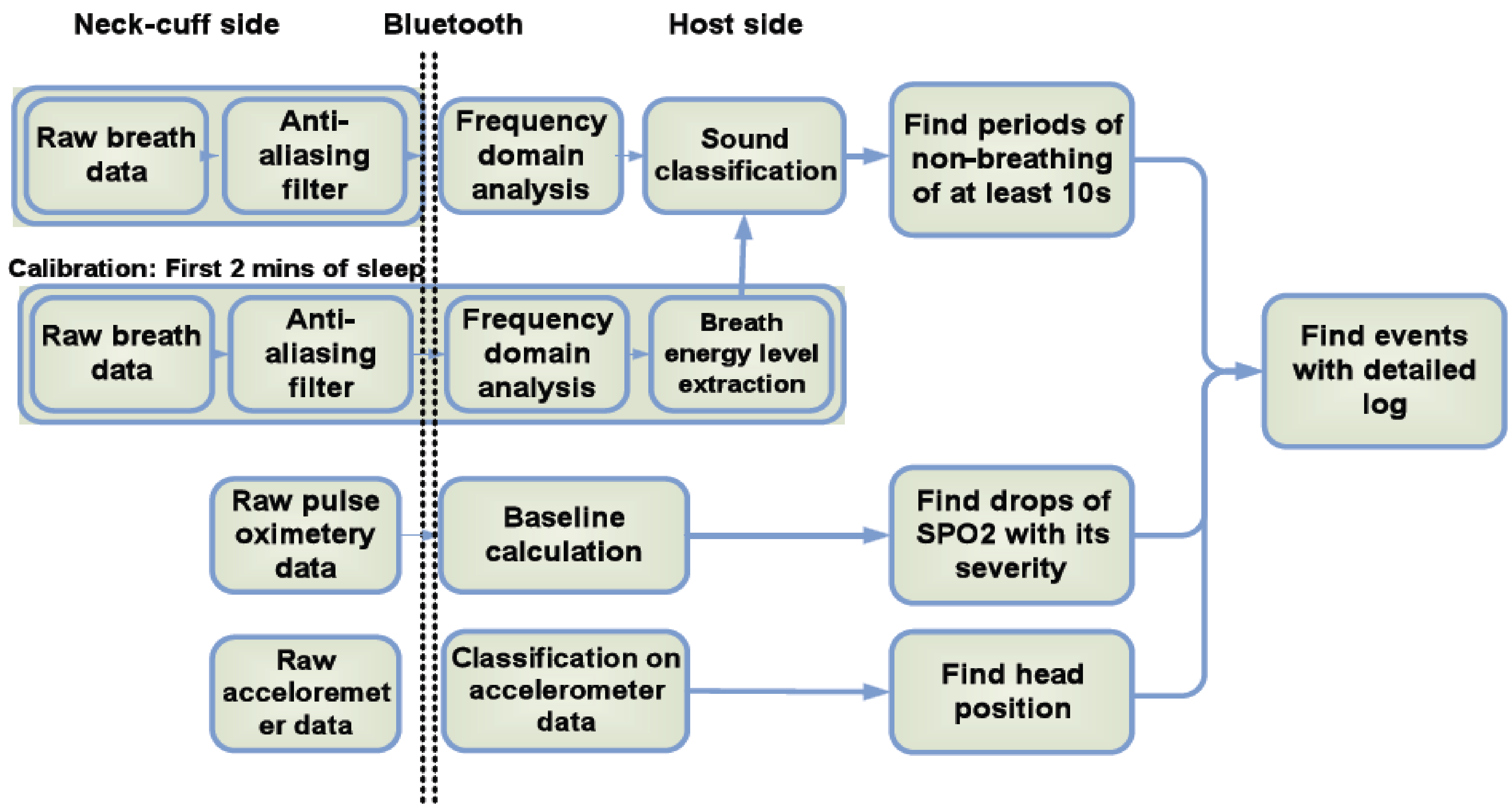
Other Hardware: Bluetooth transceiver, Bluetooth neck-cuff antenna, MSP430 micro-controller unit (MCU)

Process: Pre-process sensor data using MCU and transmit via a Bluetooth radio module to the patient-end computer; After further signal processing, transmit data via Internet to doctor’s computer





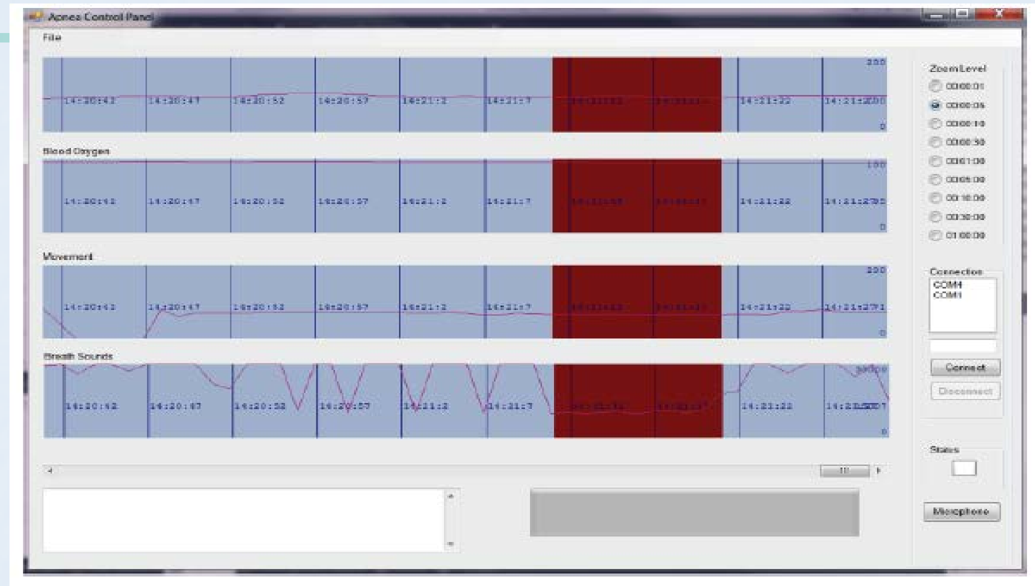
Example: Neckband Sensor Module



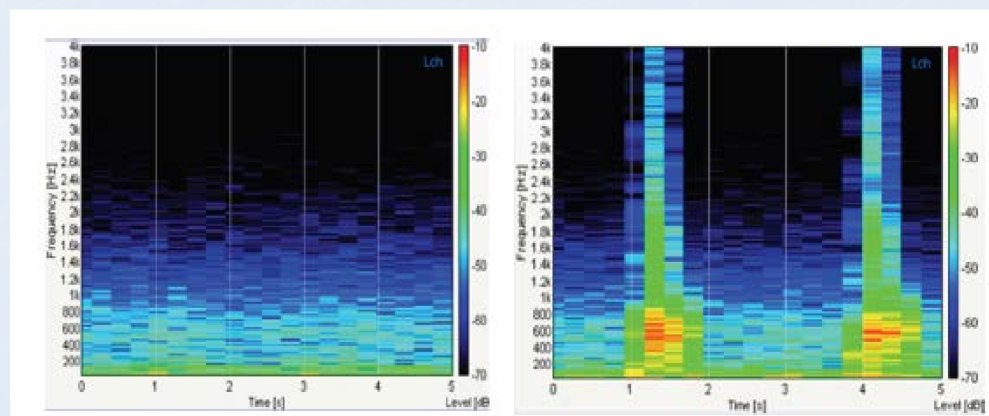
Signal Processing and Transmission

Example: Neckband Sensor Module

Doctor's View of Oximetry



Doctor's View of Stethescope Data: No Breathing (Left); Breathing (Right)



Sensor Jacket Design

Missing Link: Diagnosis

- **IMAGINE:** Medical diagnosis is by human medical professionals
- **TELEMEDICINE:** Diagnosis may be automated
- **Automated Diagnosis:** Knowledge-based decision making (A Medical Expert System) will be needed

Conclusion

- Telehealth, Telemedicine, and IMAGINE were introduced
- Rationale was provided for Telemedicine
- State-of-the-art of telemedicine was presented
- Technical issues, challenges, and possible solutions were indicated
- Highlights of the IMAGINE Project and the technological issues were indicated

UBC Industrial Automation Laboratory

Thank you!

www.mech.ubc.ca/~ial

Acknowledgments

Sponsors:

- **Xiamen University**
- **Senior Canada Research Chair (CRC 1)**
- **Natural Sciences and Engineering Research Council (NSERC) of Canada**
- **Canada Foundation for Innovation (CFI)**
- **British Columbia Knowledge Development Fund (BCKDF)**

Research Assistance:

- **Mr. Shan Xiao, Industrial Automation Lab, UBC**
- **Xiamen University researchers lead by Prof. Maoqing Li**
- **Arthur C. Clarke Centre, Sri Lanka lead by Prof. Lalith Gamage**