Some of my research projects

Monitor activities and vital signs

- Camera
- Radar
- tDCS Device
- Tongue Display Unit
- Blood Pressure
- ECG
- RFID Tag
- Stimulation
Outline

• Introduction

• Sensors

• What signals can be observed remotely

• Contactless monitoring
  – Radar
  – Camera

• Recent works and future directions
Goal

Continuous, non-invasive and unobtrusive monitoring of vital signs and activities of people
Applications

- Monitoring elderlies and patients
- Sleep apnea
- Preventive monitoring

- Ambient Assisted Living
- Stress and emotion detection
- Detecting social activities and interactions

- Wellness applications
Monitoring seniors

• Problem
  – Seniors don’t like or forget to wear wearable devices
• Main goals:
  – Fall detection
  – Fall prevention
  – Estimating level of activities during the day
Life sign monitoring in prisons

Physiology monitoring and alerting system and process, GE, 20120245479 A1, Sep. 27, 2012.
The system estimates the state of the subject as one of the three states including motion, still and concerned state based on detected motion and physiological parameters
Monitoring Heart Failure patients at home

- Congestive heart failure (CHF) occurs when the heart is unable to pump sufficiently to maintain blood flow to meet the body's needs
- Monitoring heart failure patients to reduce readmission rates
  - In 2015 it affected about 40 million people globally
  - 24% of these patients are re-admitted within a year with further decompensated CHF
  - Progress has been made in monitoring breathing patterns
    - irregular or Cheyne-Stokes respiration
    - respiration stability index (RSI)
- Goal: monitoring patients at home and relaying physiological alerts to care providers.
Respiration monitoring

- Respiration monitoring during radiation treatment
  - Measuring breathing rate during cancer radiation treatment
  - Initial experiments performed with a phantom with very encouraging results
  - Benefits: no need to put the breathing belt on the patients.

- Respiration monitoring for obstructive sleep apnea
  - Characterized by repetitive episodes of shallow or paused breathing during sleep, despite the effort to breathe
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Sensors

- **Wearable**
  - Contact-based
  - Designed to monitor physiological processes in the human body

- **Infrastructure sensors**
  - Remote:
    - Radars, cameras
    - Close proximity detection
  - Pressure mats, bed occupancy sensors
Wearable devices

- Heart rate monitoring
- Breathing rate
- Fall and activity detection
Wearable devices are great, but ...

- Not suitable for monitoring that takes weeks or month
  - You forgot to wear them
  - Or, battery problems

- Or, there are people who do not want to wear sensors
  - Dementia patients
  - People who are not comfortable with new technologies
  - Prisoners
Our focus: Long range contactless monitoring

- Distance of several meters
- Ability to monitor multiple people
- Minimum one sensor, however it is possible to have a network of heterogeneous sensors
- Sensors have to be networked and plugged in because they monitor continuously 24/7
- Monitoring and alarming needs to be performed automatically at the central station
# Wearable vs. Contactless Monitoring

<table>
<thead>
<tr>
<th></th>
<th>Wearable</th>
<th>Contactless</th>
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</thead>
<tbody>
<tr>
<td>Interfering with normal behavior</td>
<td>☹️</td>
<td>☑️</td>
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<tr>
<td>Activating monitoring system</td>
<td>☑️</td>
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<tr>
<td>Requiring compliance</td>
<td>☑️</td>
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<tr>
<td>Going outside of the range</td>
<td>☑️</td>
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<tr>
<td>Precision</td>
<td>☑️</td>
<td>☑️</td>
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<tr>
<td>Environmental problems</td>
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</tbody>
</table>
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• Contactless monitoring
  – Radar
  – Camera
• Recent works and future Directions
What can we monitor remotely

Figure is from Reference [1]: T. Teixeira, at al, “A survey of human-sensing methods for detecting presence, count, location, track and identity,” 2015.
Physical traits that can be observed

Figure is from Reference [1]: T. Teixeira, at al, “A survey of human-sensing methods for detecting presence, count, location, track and identity,” 2015.
Cardiorespiratory contactless monitoring

- Continuous monitoring of the rhythm of heart and lungs
  - Breathings
    - Breathing rate
    - Breathing pattern – repetitive shallow breathing
    - Stop-breathing events
  - Heartbeat
    - Heart rate
    - Heart rate variability
    - Pulse transit time
Cardiorespiratory contactless monitoring techniques

Figure is modified from the Reference [2]: C. Bruser at. Al. "Ambient and Unobtrusive Cardiorespiratory Monitoring Techniques," 2015.
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Challenges

• Signal of interest is often very small
• Signal is extracted in uncontrolled situations
  – E.g. trying to extract the heart rate when the subject is not oriented towards the camera or when the subject is covered.
• Environmental problems
  – Cameras: darkness, background is similar to the object that we want to monitor
  – Radar: clutter, movement at frequencies that correspond to breathing frequencies
• Distance, sensor positions, number of monitored people, cost
Biomedical radar

Software functions:
- Present physiological signals and alarms
- Breathing and heart rate estimation
- Classifying activities as moving, sitting, lying or fall

MedDev Radar Software

Off-the-shelf radar

Detecting and removing interference

Detecting movement of the chest and heart

Subject

Fan
Operation at the system level

Computer Algorithms

Radar transmitter and receiver

Subject

- Normal Breathing
- Holding Breath
- Normal Breathing

- Sitting still
- Sitting and slight body movement
- Sitting and movement of arms

Radar Signal

Time (sec)
Principles of operations

Two major types of radars:
- Continuous wave
- Pulsed (ultra wide band)

Doppler shift
- Waves reflected from the moving objects will suffer a frequency shift
- The shift is related to the object’s velocity towards or away from the radar

Micro-Doppler
- Small-periodic movements

Figure is from the Reference [3]: Droitcour, Amy Diane. *Non-contact measurement of heart and respiration rates with a single-chip microwave Doppler radar*. Diss. Stanford University, 2006.
Biomedical Radar - Applications

• Detection of stop-breathing events
  – Sudden cardiac death
  – Suicide events
• Detection of posture
  • Fallen people
• Detection of activities of people
• Sleep apnea detection

• Other applications
  – Rescue missions under rubble
  – Through-the-wall detection
  – Surveillance applications
  – Detection of the level of stress
  – Road safety in cars
  – Occupancy sensors
  – Human computer interaction through gesture identification
Biomedical Radar - Experiments
Ranging and Detection of breathing

June 12, 2014
High level processing of radar signals

- Detecting the person
  - Energy of the signal
  - Looking at the probability distribution of the signal over time
- Locating the person
- Classifying the activity of the person
  - Supervised learning
- Breathing estimation
- Posture and fall detection
- Alarm generation
Classification of activities for 9 cases

1- Sitting on a chair as still as possible while breathing normally
2- Sitting on the chair and randomly moving the head
3- Sitting on the chair and randomly moving the torso.
4- **Sitting on the chair as still as possible while stop breathing for 20 seconds in every minute.**
5- Sitting on the chair as still as possible while breathing normally with water movement.
6- Sitting on the chair as still as possible while breathing normally with fan on. A fan was placed in front of the subject and was set to medium speed.
7- No subject in the room with water movement. The water movement was simulated as in the Event #5.
8- No subject in the room with fan on. The fan was set as in the Event #6.
9- No subject in the room.
Classification of activities for 9 cases

<table>
<thead>
<tr>
<th>Linear Bayesian Radar Pattern Classifier</th>
<th>Stationary detection</th>
<th>Stop-breathing detection</th>
<th>Interference detection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy</td>
<td>93.06%</td>
<td>89.47%</td>
<td>86.30%</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>94.08%</td>
<td>88.24%</td>
<td>85.00%</td>
</tr>
<tr>
<td>Specificity</td>
<td>91.40%</td>
<td>90.68%</td>
<td>87.21%</td>
</tr>
</tbody>
</table>
Data Quality

• Unsupervised data collection, motion artifacts

• Quality of the data being recorded and processed:
  – Raw data quality: identity and quantify noise, artifacts, activities ...
  – Data aggregation quality: data fusion
  – Location quality: position, body posture, etc.
  – Quality of the estimated: your heartrate is higher than usual.

• Requires data quality indicators and uncertainty quantification
Confidence intervals for estimated breathing rate from the radar signal

Fig. 1: The scenario where a subject is placed in front of the radar. Chest, abdomen and heart move periodically.
Confidence interval for estimating breathing rate from the radar signal, cont.

\[ f_{est} = \mu_{est} = \text{mean}(f_i) \quad \sigma_{est} = \text{std}(f_i) \]

95\% confidence interval = \([\mu_{est} - 1.96\sigma_{est}, \mu_{est} + 1.96\sigma_{est}]\)
Confidence interval for estimating breathing rate from the radar signal, cont.

- We are using bootstrapping method in order to find a confidence interval for each estimation method.
  - Every 3 seconds the last 30 seconds are considered.
  - 100 random 15 seconds are chosen and one estimation is given for each segment.
  - Mean and variance of estimations is calculated
  - Mean of estimation error is calculated
Experimental data: Stationary subject sitting in front of the radar

Signal in the zone of interest

Radar Signal

Time (sec)

Estimation (bpm)

Estimation
Lower Limit
Upper Limit

Time (second)
Challenges

• Identifying a person
• Challenges with breathing estimation
  – Both chest and abdomen move due to breathing
  • Nonlinear nature of radar signal generates harmonics of vital signs alongside with their multiple inter-modulations.
  – Posture and position affect the strength and other characteristics of received signal
  – Detect stop-breathing events
Cameras

- Cameras are ubiquitous and inexpensive
- Camera can detect:
  - Posture
  - Activity
  - Detect and identify multiple people
  - Displacement of the chest - Breathing rate
  - Heart rate – Blood Volume Pulse
Video processing steps [4]

- Presence
- Identification
- Posture detection
- Activity detection
- Breathing and heartbeat estimation
Video signal - PPGi

- Photo-plethysmography imaging (PPGi) is noninvasive way of sensing the cardiovascular blood volume pulse through variations in transmitted or reflected light
- Skin change its optical properties with perfusion
Video signal - surface displacement measurement

Figure is from the Reference [2]: C. Bruser et. Al. "Ambient and Unobtrusive Cardiorespiratory Monitoring Techniques," 2015.
Challenges

- Motion tolerance
- Ambient light and environmental variations
- Region of interest optimization
- Image enhancement and visualization
  - Eulerian Video Magnification
Fall detection

• Learning and recognizing a human shape and detecting a feature of the moving person.
• Fall-down comprises at least one of:
  – temporal sequence indicates a transition from an upright to a lying pose;
  – motion characteristics indicates a downward motion within a predetermined time period; and
  – there is an abrupt change in the trajectory for the object of interest.
3D camera applications

3D camera measures depth based on illuminating the scene with a controlled light source and measuring the backscattered light.

- Video games
- Game-based rehabilitation exercises
- Robotics
- Compensating for patient movement during medical imaging
- Fall detection
- Sign language recognition
Outline

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• Traditional approaches
• What signals can be observed remotely
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Using mobile phone as a sonar to detect breathing rate [6]

- Uses smartphone’s speaker as an active sonar transmitting sound waves at 18-20 kHz
- Chest and abdomen motions create changes in the reflected sound wave
- Reflected sound wave is detected using smartphone’s microphone
- Application: sleep apnea
- Experiment: 87 patients and 57 healthy subjects
- 98% accuracy in detecting obstructive sleep apnea
- Very high accuracy in classifying levels of sleep apnea
Wireless infrastructure for detecting vital signs: WiBrethe [8]

- The human body acts as a reflector of the wireless signal.
- The minute chest and abdomen movements amplitude-modulate the wireless signal before it reaches the receiver.
- Respiratory rate is extracted from the periodicity of the amplitude modulation.
- Error: 2.16 breaths per minute
Future Directions in the Field

• Problems
  – People detection in uncontrolled environment
  – Multiple people identification and tracking
  – Supervised algorithms trained only for a number of specific cases

• Potential directions
  – Improvements of the sensors or new sensors
  – Sensor fusion at the massive scale
  – Inferring actions and conditions using unsupervised learning techniques
  – Inferring complex actions
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References


