# Contactless Heart Rate Variability Measurement

## by IR and 3D depth sensor (Microsoft Kinect 2) with respiratory sinus arrhythmia

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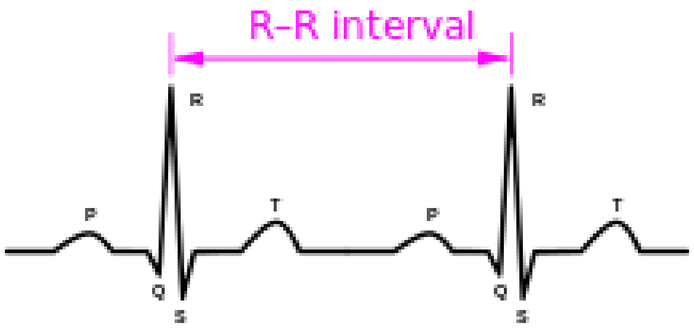
# Outline

- Heart Rate Variability (HRV)
- Background
- Heart Rate Devices
- Problem Statement
- Methodology
- Experiment Design
- Results
- Discussion
- References
- Q&A

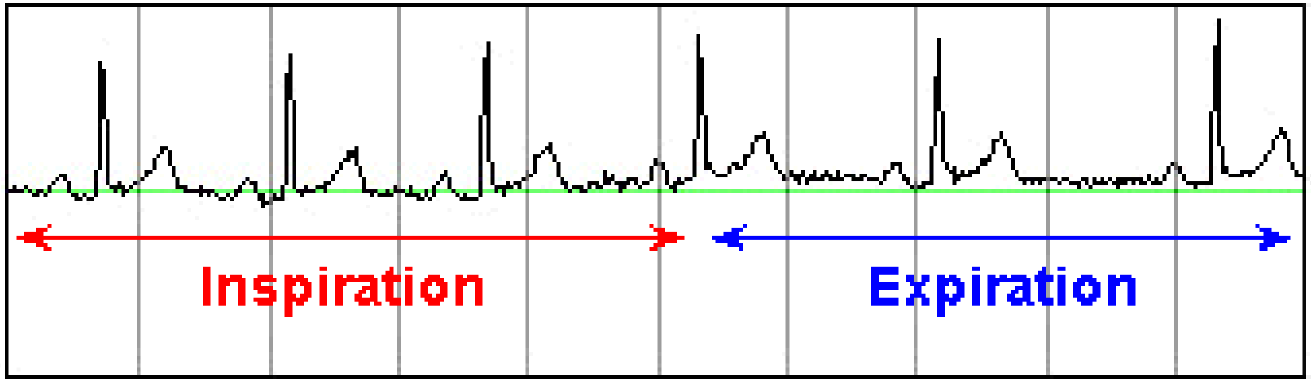
# Heart Rate Variability (HRV)

- Heart rate variability (HRV) is defined as the physiological phenomenon of variation in the time difference between sequential heartbeats.
- Nowadays, the growing popularity of healthcare and fitness tracking devices among people has also stimulated the use of HRV analysis in other research areas, such as HCI and affective computing (AC).
- HRV is correlated with user's arousal and ego depletion state, intelligent systems can consider HRV to deliver more adaptive content to the users.



# HRV Fluctuations

- ***Low-frequency oscillations:*** This heart rate variation is associated with Mayer waves (Traube–Hering–Mayer waves) of blood pressure and is usually at a frequency of 0.1 Hz or a 10-second period.
- ***Respiratory arrhythmia (or Respiratory sinus arrhythmia - RSA)***: This heart rate variation is associated with respiration. It is a vagally mediated modulation of heart rate such that it increases during inspiration and decreases during expiration due to the connection of the heart and lungs via pulmonary artery.

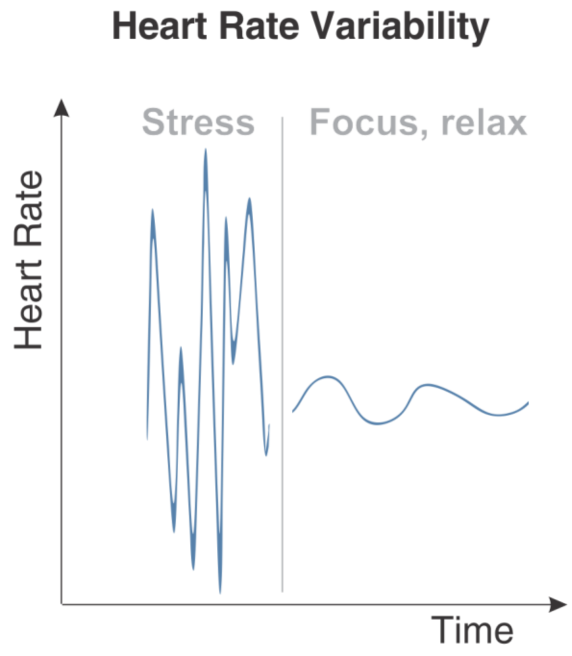


# HRV – Respiratory Ratio

- Normal resting heart rate: 60 and 80 beats per minute.
- Resting respiratory rate: 12 and 20 breathes per minute.
- Both respiratory and heart rate increase by exercise with the ratio of 4 heartbeats over 1 breath.
- The ratio between the heart rate and respiratory rate is mostly maintained, but it varies from one person to another based on the health, age and fitness activities.
- The healthy ratio is between 3 (60 BeatsPM / 20 BreathsPM) and 8 (100 BeatsPM / 12 BreathsPM).

# Background

- Lower arousal states cause higher HRVs. A high HRV is correlated with a better health.
- HRV is controlled by the human autonomic nervous systems:
  - 1) Parasympathetic nervous system (PNS): It decreases the heart rate and increases HRV.
  - 2) Sympathetic nervous system (SNS): It increases the heart rate and decreases HRV.
- A sudden drop in HRV is a sign of overtraining and fatigue, and the person needs time and rest to recover.
- Cognitive depletion would cause lower HRV, and it is also an index for the self-control power.



# Heart Rate Devices

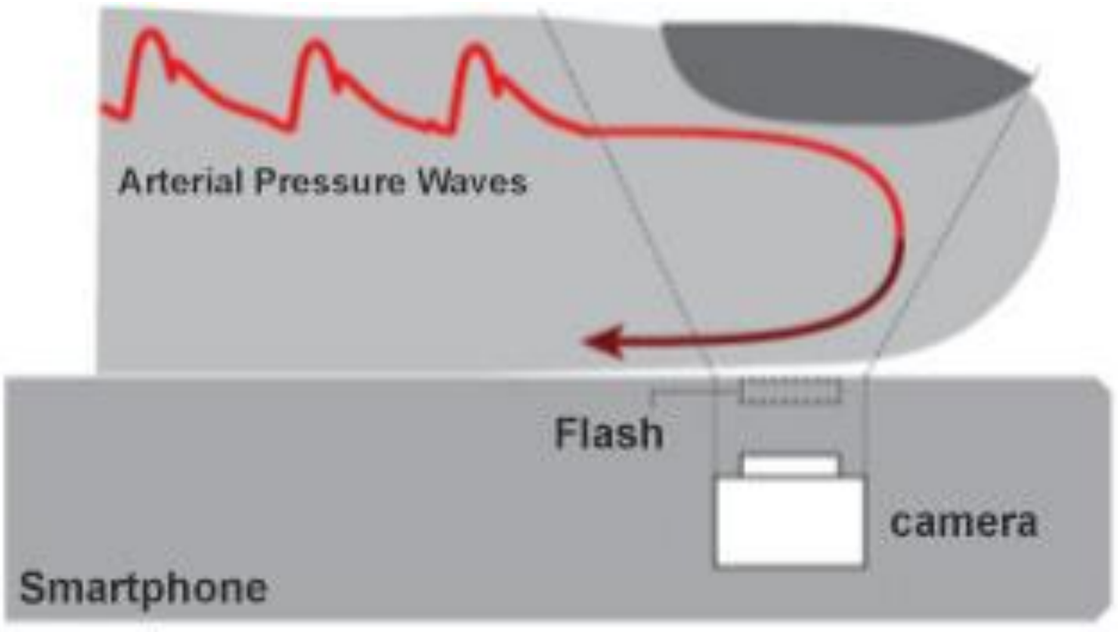
- Heart Rate Polar Belt (Electrocardiography)
- ECG
- PPG Based Devices
  - PPG Sensor
  - Smart Phone Camera
- Contactless Devices
  - Microsoft Kinect 2 Heart Rate

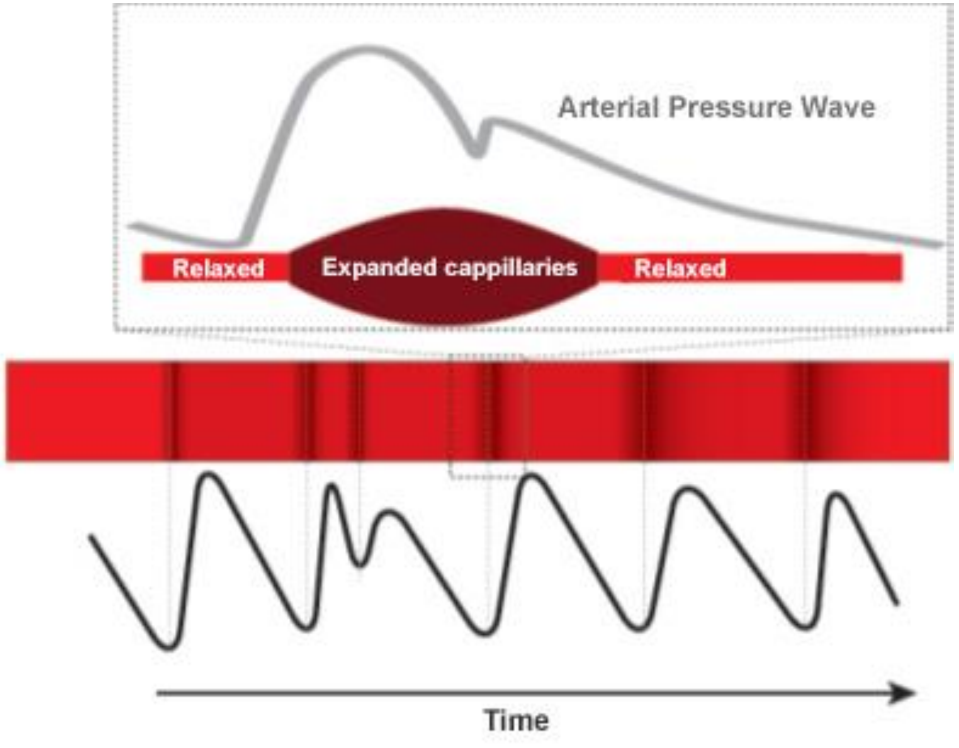
# Heart Rate Polar Belt (Electrocardiography)

- Heart Rate monitor chest strap (Heart rate polar belt) senses the electrical signals of the heart.
- When the heart beats, a small electrical signal is sent through the heart muscles causing a heartbeat.
- There are electrodes in the shiny plastic part on the back of the belt, and they can pick the sent electrical signal.
- Heart rate belts usually record the R-R intervals with a fine resolution of 1ms.

# Smart Phone Camera

The arterial pressure wave can be measured, and by analyzing the pressure waves, the heart rate data can be extracted.



# Microsoft Kinect 2 (Xbox One)

# Microsoft Kinect 2

- When a person's heart pumps blood, the volume of blood is pushed through various veins and muscles. As the blood pumps through the muscles, particularly the face, it causes a minor heat changes on skin, and also more light are absorbed, and the less brightness a web camera sensor picks up. These changes in brightness and heat values are very tiny and can be extracted using mathematical methods. These changes are periodic and they generate a signal. If the signal is matched with a blood pulse, the heart rate can be calculated.
- In order to match the change in brightness and heat to a blood pulse, we have used the Independent Component Analysis (ICA) concept. This concept is the basis for finding hidden signals within a set of mixed signals. If there are two people talking in a crowded room, and there are microphones placed at various locations around the room, ICA algorithms can take a mixed sample of signals, and calculate an estimated separation of components. If the separated components are matched to the original signal of a person speaking, the target person has been found in the crowded room.
- The ICA concept is also known as blind source separation, and this project uses the JADE algorithm in R, to provide the separation matrix of components for the R, G, B, and IR mixture of data. Then the separated components have their signals extracted using a Fast Fourier Transform to find a matching frequency range of a heart rate.

# Problem Statement

- Almost all of the known HRV devices require to be attached to the subject's body that is not desirable in advanced HCI applications. Therefore, there is a lack of a proper method to monitor heart rate with a higher usability and a reliable performance, which is practical for individuals in HCI and AC areas.
- A reliable contactless method would be a desirable solution, but its precision is still in question.

**Objective**:

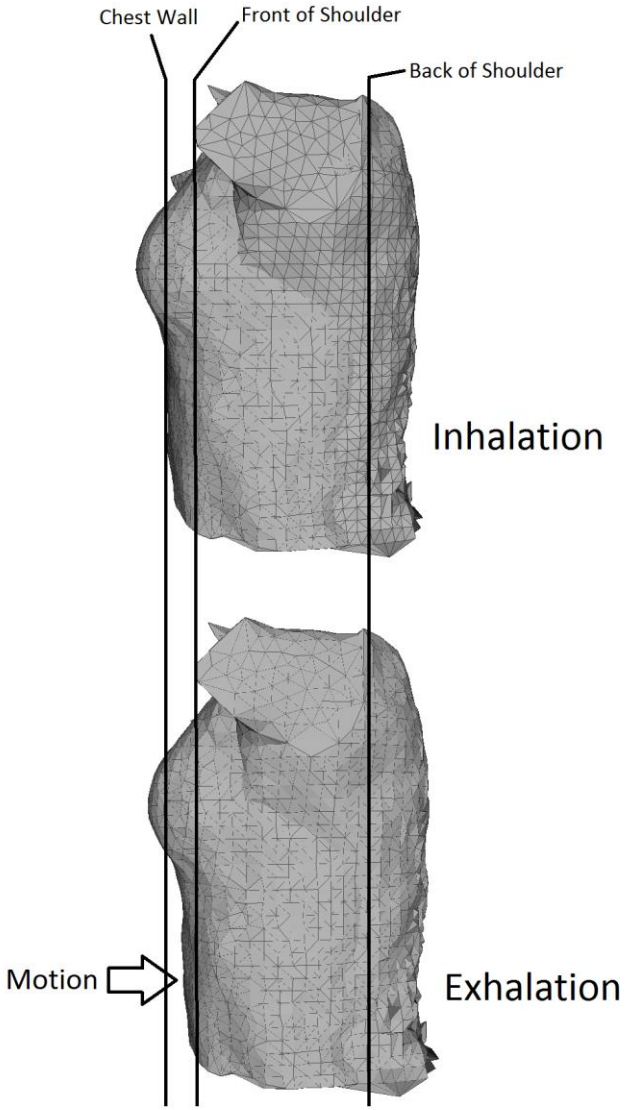
- To improve Microsoft Kinect 2 Heart Rate measurement accuracy by considering the RSA

# Methodology

- HRV is associated with respiration. HRV increases during inspiration and decreases during expiration. By having an accurate heart rate signal from a healthy subject, the respiratory signal can also be measured, and also, on the other hand, the next heart rate can be estimated by considering the respiratory signal.
- When the first derivative of the respiratory signal changes the sign (or equal to zero), the respiration state is being changed. The second derivative of the signal says if the change is to the inspiration or expiration state. At this moment of respiratory state change, RSA is being expected, so the next HR would be estimated by applying the RSA variation.
- Then the actual measured heart rate would be compared with the estimated HR to calculate the possible error value.

# Kinect 2: Respiration Monitoring

- When a subject is inhaling, the rib cage moves upwards and outwards, and the air is drawn int the lungs. In this case, the chest is getting closer to the 3D sensor, and when exhaling the reverse procedure occurs and the chest would go downwards and backward, and it is getting further from the sensor.
- Thus, the local minimum in the signal is the inspiration trough and the local maximum is the expiration peak in the respiratory signal from th 3D depth sensor.

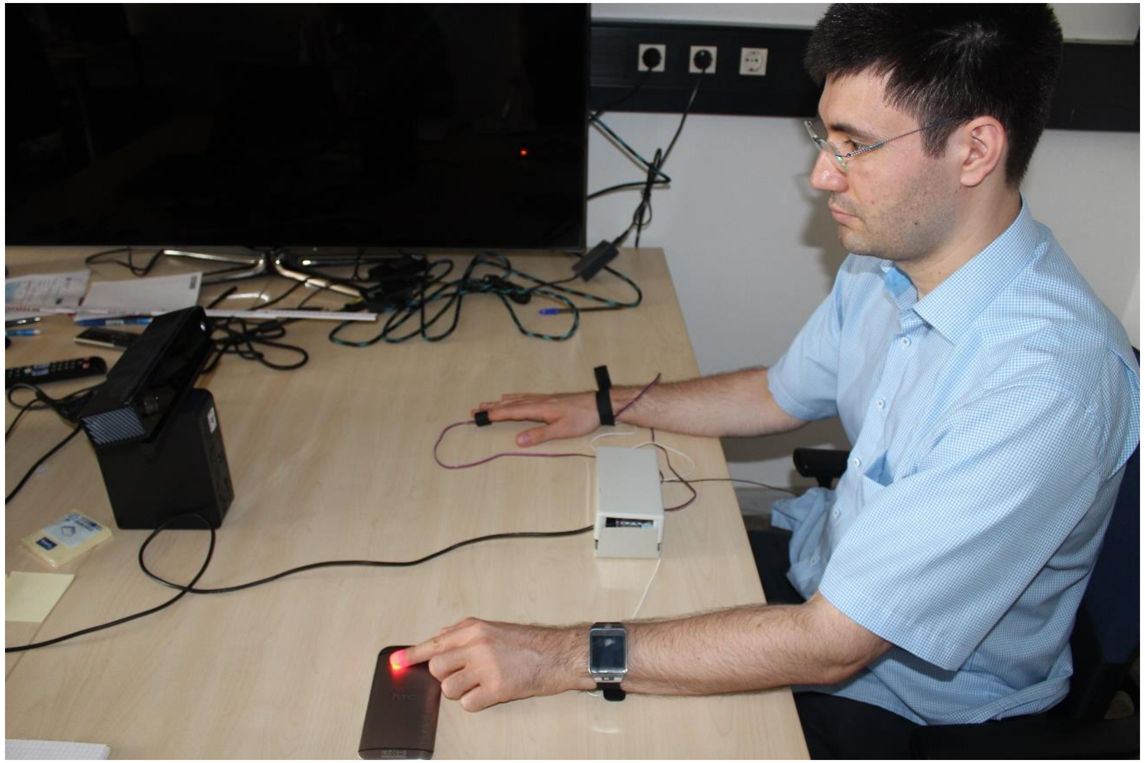


# Methodology

| Algorithm 1. Pseudocode of heart rate correction with RSA | |
|---|---|
| Var ← 108ms | //Initializing the variation value |
| function HRCorrection ($RR_i$) | |
| if sgn(rsf′(i)) != sgn(rsf′(i-1)) then | //A respiration change is happening |
| if f′′($RS_i$) > 0 then | //Inspiration |
| $\widehat{RR}_{i+1} \leftarrow RR_i - Var$ | |
| else | //Expiration |
| $\widehat{RR}_{i+1} \leftarrow RR_i + Var$ | |
| end if | |
| $RR_{i+1} \leftarrow$ Performing HRV calculations | |
| $RR_{i+1} \leftarrow Average(\widehat{RR}_{i+1}, RR_{i+1})$ | |
| $Err \leftarrow \widehat{RR}_{i+1} - RR_{i+1}$ | |
| Var ← Var – Err | |
| end if | |
| return ($RR_{i+1}$) | |
| end function | |

# Experiment Design

- Recording simultaneously on 5 subjects for minimum 60 seconds
- Devices:
  - HR Belt
  - 2 PPG Sensors
  - RGB Camera
  - Microsoft Kinect 2
    - Respiratory
    - Heart Rate



# Results

All the tested devices were validated against the chest strap (Polar) as a gold standard device.

The suggested methodology could increase the accuracy of the measured HRV for about 3%.

| | Camera | Camera_Inv | PPG1 | PPG1_Int | PPG2 | PPG2_Int | Kinect2 | Kinect2-RSA |
|---|---|---|---|---|---|---|---|---|
| **Mean Values** | 0.63 | 0.572 | 0.410 | 0.495 | 0.451 | 0.508 | 0.539 | 0.571 |
| **Max Values** | 0.918 | 0.699 | 0.673 | 0.779 | 0.673 | 0.798 | 0.664 | 0.681 |

# Discussion

- The results show that the HRV accuracy by applying the RSA estimation can be increased.
- To present the strength level of agreement for each parameter, McBrides scale has been used.
- According to this scale Kinect 2, Mean HRV of Kinect 2 is 0.950 and Kinect2-RSA is 0.969.
- According to the McBrides scale, the resulted agreements of Kinect 2 are not “Perfect” but “Substantial”.
  - The agreement values > 0.99 = Perfect
  - The agreement values between 0.95 to 0.99 = Substantial

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# Q&A