

# Systolic Pressure Modulation

a time-consistent variant of  
Systolic Pressure Variation

Sjoerd Diepen

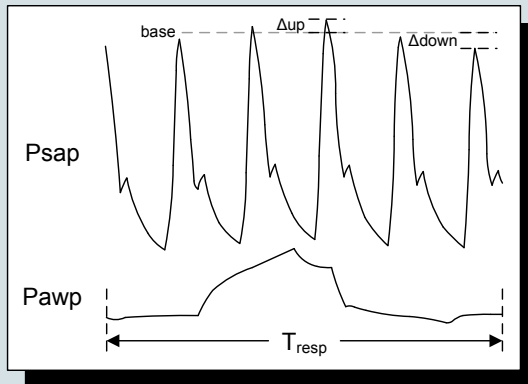
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## Overview

- What is SPV
- Problems SPV
- SPV and Amplitude Modulation
- Results
- Conclusions

# 1. What is SPV

- Patients undergoing positive pressure ventilation (surgery/ICU)
- Observation: cyclic changes in arterial blood pressure, related to respiratory cycle



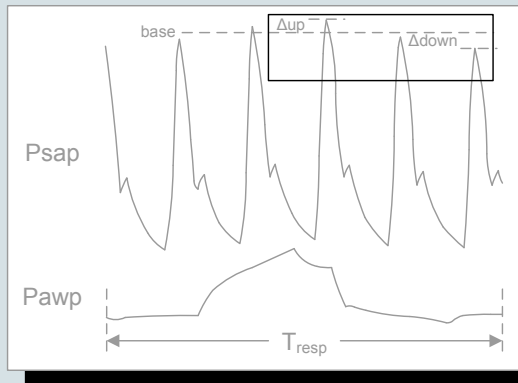
Define Systolic Pressure Variation (SPV) for each respiratory cycle:

$$\begin{aligned} \text{SPV} &= \text{peak}_{\text{max}} - \text{peak}_{\text{min}} \\ &= (\text{peak}_{\text{max}} - \text{peak}_{\text{baseline}}) + \\ &\quad (\text{peak}_{\text{baseline}} - \text{peak}_{\text{min}}) \\ &= \Delta_{\text{up}} + \Delta_{\text{down}} \end{aligned}$$

- SPV (in particular  $\Delta_{\text{down}}$ ) related to hemodynamic aspects

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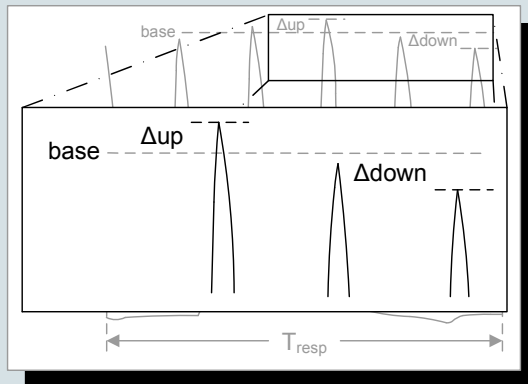
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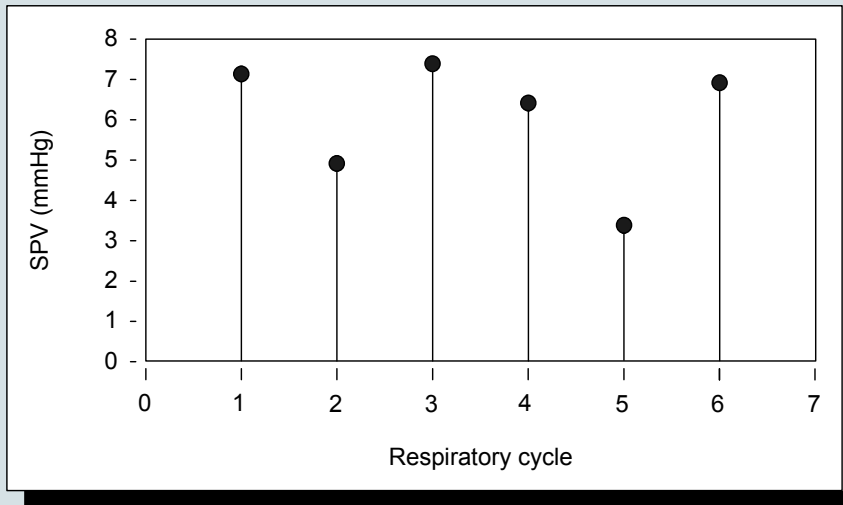
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- SPV (in particular Δdown) related to hemodynamic aspects

## 2. Problems SPV

- SPV not time consistent
  - high amplitude fluctuations for subsequent respiratory cycles



- Fluctuating SPV values difficult to relate to (changing) hemodynamic aspects

## 2. Problems SPV

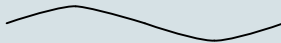
- Solve fluctuations by averaging:
  - past  $N$  calculated SPV values
    - \* due to arrhythmias and artifacts  $N^{th}$  cycle can be a 'long' time ago
  - calculated SPV values of past  $T$  seconds
    - \* due to arrhythmias and artifacts altering number of SPV values contained in the sliding time window  $T$
- More consistent values
- Sensitivity affected (lower than 'should')

### 3. SPV and Amplitude Modulation

- Carrier (frequency  $f_c$ )



- Base signal (frequency  $f_s$ )



- AM signal (Carrier x Base signal)



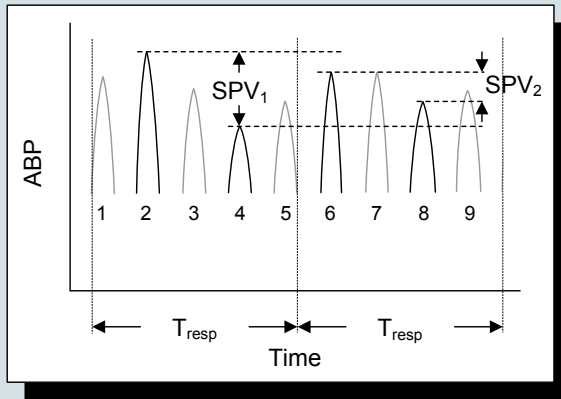
### 3. SPV and Amplitude Modulation

- Heart rate semi-independent of ventilation signal/rate:
  - quasi constant
  - not an integer multiple
- Model systolic peaks being the AM signal's peaks (i.e. samples of the envelope)
  - frequency carrier signal = heart rate
  - frequency base signal = ventilation rate



### 3. SPV and Amplitude Modulation

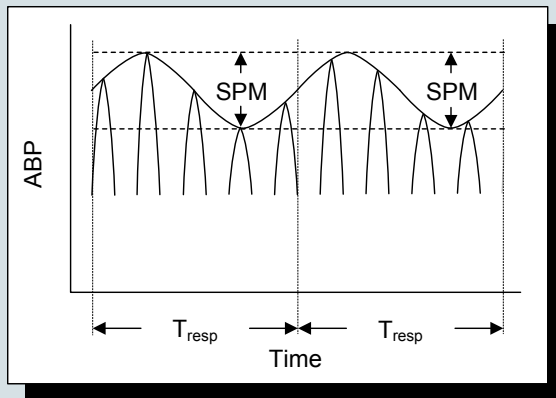
- $f_c \bmod f_s \neq 0$ 
  - Systolic peaks have differing alignments each cycle



- $\text{peak}_{\max} - \text{peak}_{\min}$  fluctuates for subsequent cycles
- Hence, SPV fluctuates

### 3. SPV and Amplitude Modulation

- Define Systolic Pressure Modulation (SPM):

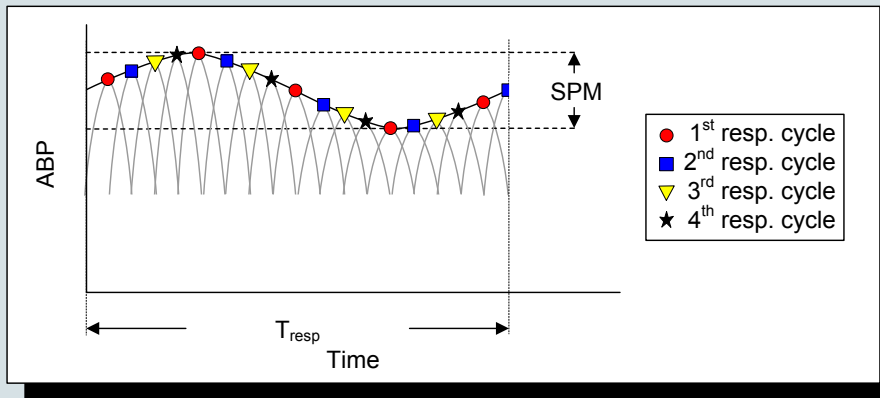


$$\begin{aligned}
 \text{SPM} &\stackrel{\text{def}}{=} \Delta\text{up}_{\text{envelope}} + \Delta\text{down}_{\text{envelope}} \\
 &= (\text{envelope}_{\text{max}} - \text{envelope}_{\text{baseline}}) + \\
 &\quad (\text{envelope}_{\text{baseline}} - \text{envelope}_{\text{min}}) \\
 &= \text{envelope}_{\text{max}} - \text{envelope}_{\text{min}}
 \end{aligned}$$

- SPM should result in a time-consistent value

## 4. Results

- No a-priori envelope information available (based on physiological model)
  - Synchronization of multiple cycles to 'increase heart rate'
  - Curve fitting by spline



- Realtime [demonstration](#) (offline)

## 4. Results

- 5 Arbitrary patients (data from Catharina Hospital Eindhoven and IBIS project)
- Stable period of 1 minute

Patient	$\mu_{SPV}$ ( $\sigma_{SPV}$ )	$\mu_{SPM}$ ( $\sigma_{SPM}$ )
1	2.07 (0.60)	2.59 (0.22)
2	6.62 (1.87)	7.20 (0.22)
3	3.60 (1.96)	3.42 (0.25)
4	6.04 (1.18)	6.39 (0.40)
5	7.00 (0.97)	7.57 (0.27)

(values in mmHg; SPM window 1 minute)

- Similar results for more than 20 patients

## 5. Conclusions

- SPV
  - Not time-consistent
    - \* Fluctuates for subsequent cycles
  - Averaging improves consistency
    - \* Partly suppresses fluctuations
    - \* Due to arrhythmias and artifacts not clear
    - \* Decreases sensitivity
  
- SPM
  - Time-consistent
    - \* Curve fitting fails if number of samples is too low
    - \* A-priori envelope information necessary
      - Physiological model needed to determine envelope information