Evaluation of Pressure Recording Configuration Effects on Pressure-Waveform Derived Cardiac Output Measurements

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Introduction

- Advances in physiologic signal processing has provided less/noninvasive cardiac output (CO) estimation methods based on arterial blood pressure (BP) waveform analysis.
- However, differences between different equipment and monitors used in signal acquisition or processing can potentially affect the morphology and dynamics of a physiologic signal.
- Catheter-tubing configurations with inappropriate damping properties deform the arterial BP waveforms; hence distorting the hemodynamic features extracted from these waveforms.
- Standards such as IEC 60601-2-34 [1] include bandwidth requirements on the pressure signal; this specification may be insufficient to support the performance of a novel downstream algorithms applied to the signal.

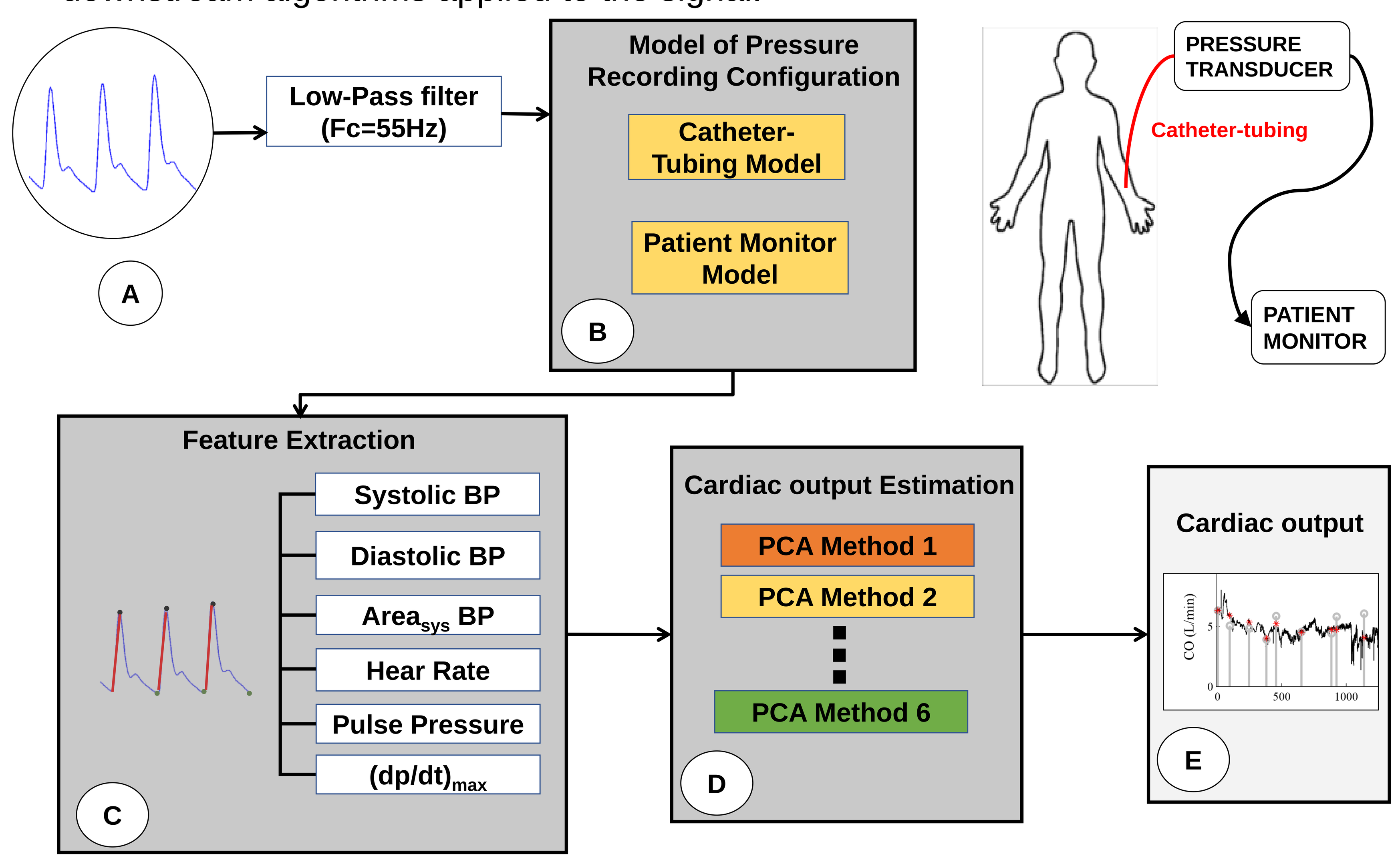


Figure 1. Block diagram illustrating the model-based procedure for obtaining pressure-derived cardiac outputs using pulse contour analysis (PCA) method.

Objective

- We investigated the effect of pressure recording configurations on performance of pressure-derived cardiac output measurements through model-based analyses.
  - ✓ We assessed the extent that different catheter-tubings distort pressure signals and pressure-derived cardiac output measurements.

Data Collection

- Arterial pressure and pulmonary artery blood flow signals were obtained from previously reported animal experiments in a protocol approved by University of Texas Medical Branch Institutional Animal Care and Use Committee [2].
- Arterial pressure was recorded from a femoral artery using a fluid-filled catheter system and pulmonary artery blood flow was recorded from a flow-probe providing a continuous reference CO measurement.

Analysis Methods

- **Model identification:** A bench setup was also used to implement a series of frequency sweeps (ranging from 1 to 100 Hz) to obtain surrogate models for pressure recording catheter-tubings and monitors.
- We measured the frequency responses of several catheter-tubings and pressure monitors.
- Second-order and Bessel filter models were identified to simulate the behavior of catheter-tubings and pressure monitors based on the data obtained from the frequency sweep.
- We verified these models by comparing animal arterial BP waveforms passed through the actual system (catheter-tubings, monitors) and simulated with the transfer functions.

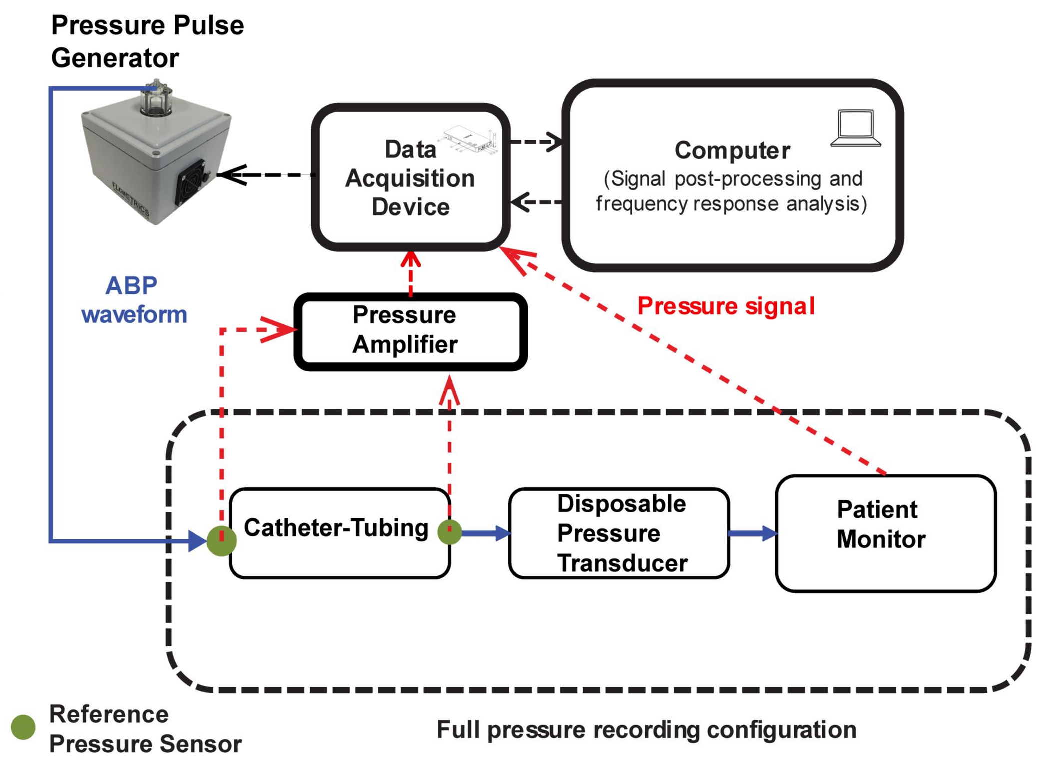
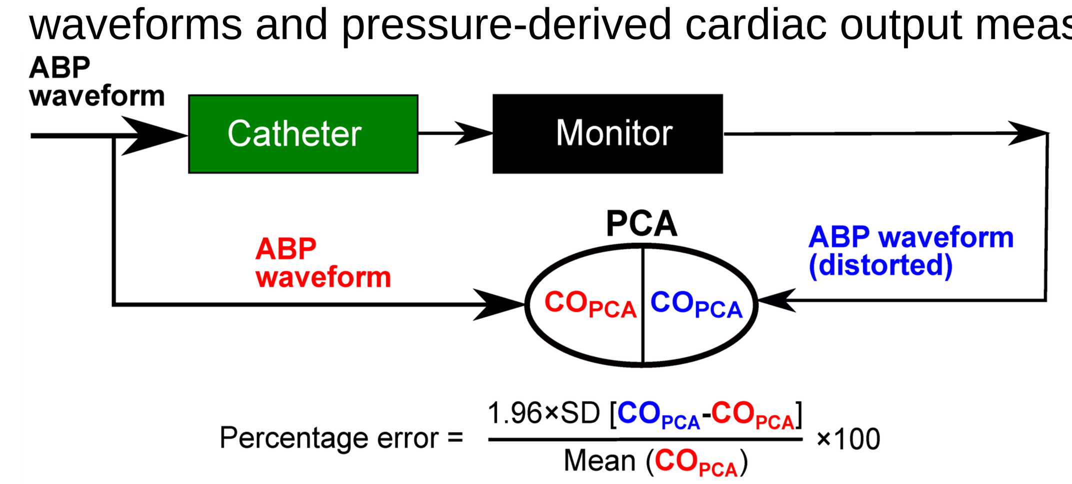


Figure 2. Schematic figure illustrating a bench setup for replicating BP waveforms and executing frequency sweeps to obtain surrogate models for pressure recording catheter-tubings and monitors.

- **Our model-based analysis** quantifies how pressure recording configurations with different dynamic properties can influence parameters derived from blood pressure waveforms and pressure-derived cardiac output measurements.



$$\text{Percentage error} = \frac{1.96 \times SD\,[CO_{PCA} - CO_{PCA}]}{\text{Mean}\,(CO_{PCA})} \times 100$$

Figure 3. Block diagram illustrating the model-based procedure for obtaining the error in pressure-derived cardiac outputs in reference to those obtained from undistorted arterial BP (ABP) waveforms.

- ✓ Six different previously described [2] pulse contour analysis (PCA) methods were implemented.
- ✓ Change in the CO was measured for different pressure configurations.

- Catheter-tubings with different natural frequencies (F_n) and damping ratios (ζ) and patient monitors with different bandwidths were evaluated.

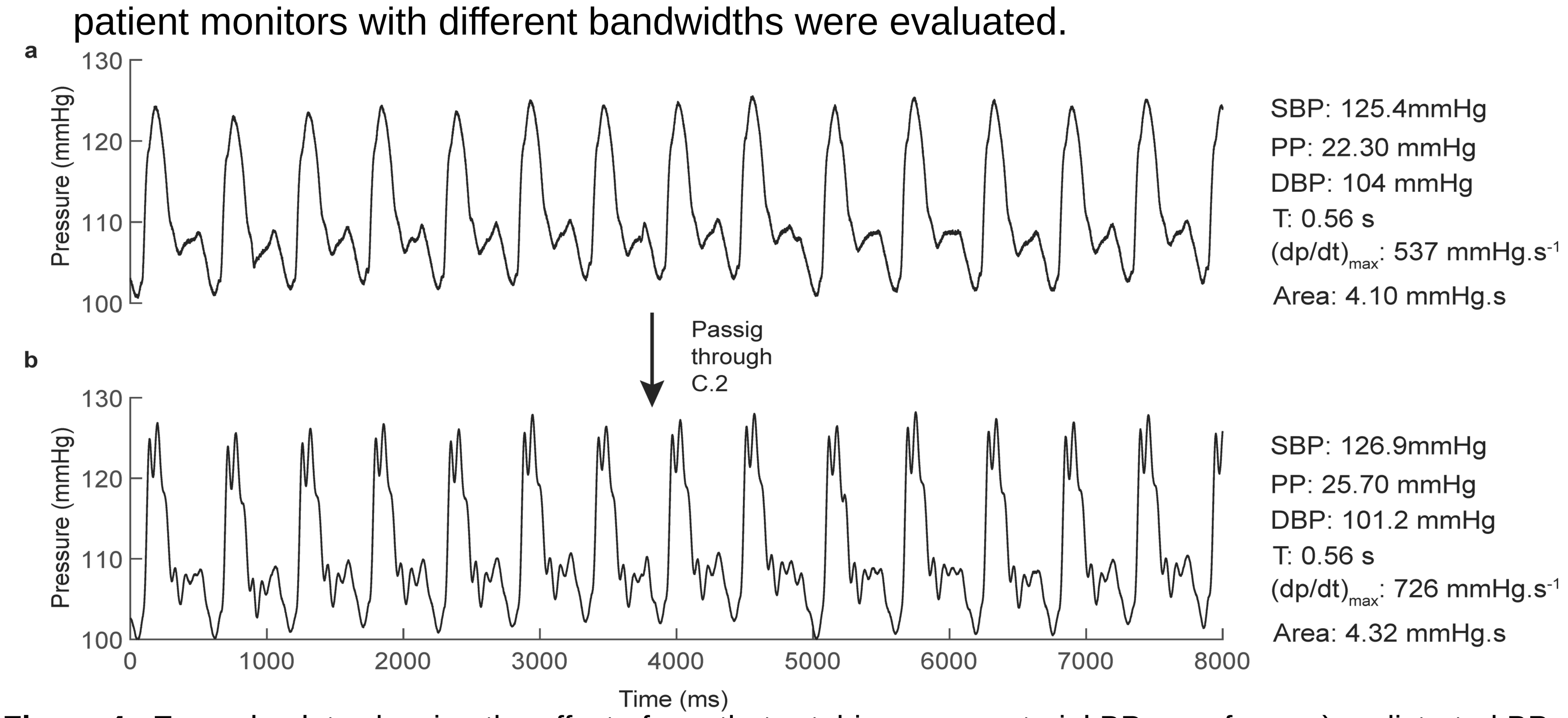


Figure 4.. Example plots showing the effect of a catheter-tubing on an arterial BP waveform. **a**) undistorted BP waveform **b**) distorted BP waveform due to a catheter-tubing (C.2).

Results and Conclusions

- Studies have suggested a total error of less than ~±30% between the test and reference methods for validating cardiac output measurement techniques based on the inherent error of ±20% for the test method and ±20% for the comparison method [3].
- Our analyses for pulse contour cardiac output measurements showed that the error of the test method varied by as much as 20% solely by changing the fluid-filled catheter tubing configuration, highlighting the importance to study the device with final configurations.
- **Conclusions:** Hemodynamic parameters derived from blood pressure waveforms can be affected by the dynamic properties of the pressure recording configurations.
- Model based approach provides a valuable tool to further understand the limitations and determine input specifications for hemodynamic monitoring systems. For instance, multi-modal machine learning-based physiologic monitoring algorithms where the specific features of the physiologic signals that influence the model may be unknown and interoperable configurations where signals coming from different monitors may be used.

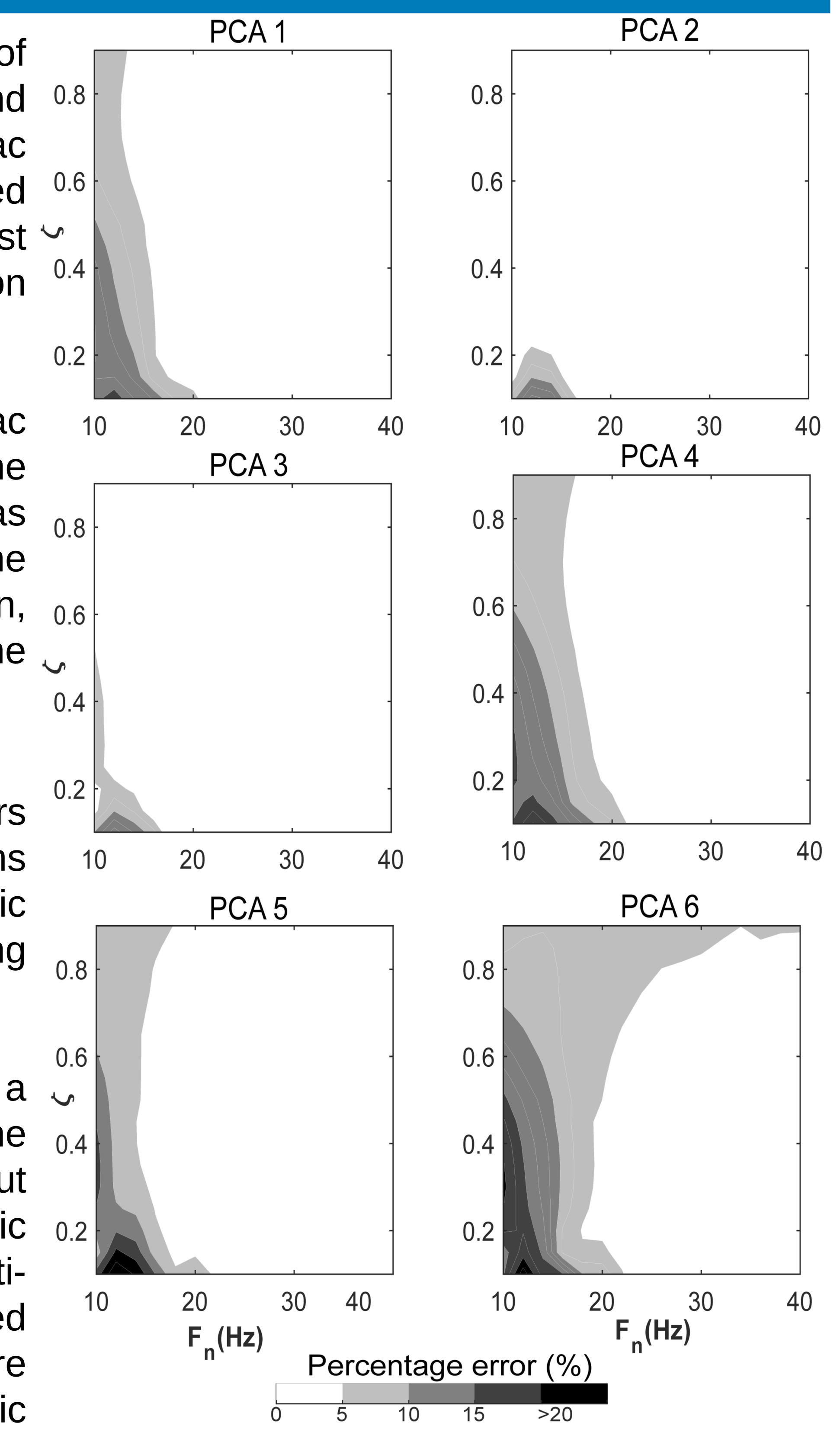


Figure 5. Plot showing percentage error of pulse contour cardiac output values from model-based analysis using a catheter with a natural frequency of F_n and damping ratio of ζ. Cardiac outputs were calculated using six different PCA methods.

References

1. I.-I. E. Commission, IEC 60601-2-34, 2011.
2. Scully et al., Shock, 43(5), 2015.
3. Critchley et al., J Clin Monit Comput. 1999.

Acknowledgements

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