

# Jugular Venous Pulse Waveform Acquisition using Contact Piezo Sensor: A Pilot Study

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**Abstract**—The jugular venous pulse (JVP) is an important signal for detecting cardiovascular abnormalities pertaining to the right atrium. The gold standard technique of central venous line catheterization is invasive, risky, and demands expertise and hence performed only in critical care settings. Non-invasive approaches such as ultrasound and photoplethysmography are used for JVP measurement but are limited by usability issues related to the operator's expertise. In this pilot study, we demonstrate the feasibility of acquiring JVP signals from the jugular veins (JV) using a contact piezoelectric sensor. The JVP piezo signals were acquired from 20 healthy participants and were validated against the reference ultrasound approach. The piezoelectric system could capture high-fidelity JVP signals at a resolution of 0.25 ms. The developed cycle segmentation algorithm was implemented to extract individual JVP cycles. The JVP cycles captured using the proposed and the reference methodologies yielded a correlation of 0.90 and a root mean square error (RMSE) less than 0.35. The developed pulse contour analysis algorithm evaluated the beat-to-beat JVP fiduciary marker locations with a maximum coefficient of variation of 17 %. The piezoelectric sensor measurements were more susceptible to motion artifacts in comparison to the reference ultrasound system. To our knowledge, this is the first use of contact piezo sensors for direct measurement of JVP signals. Future advancements based on this technique can provide viable options for ambulatory and self-measurement-based cardiac health screening.

**Keywords**—Jugular venous pulse, piezoelectric sensor, pulse contour markers, central venous line catheterization

## I. INTRODUCTION

As per the recent World Heart Federation reports, cardiovascular diseases (CVDs) continue to be the predominant death bearer globally, accounting for one-third of global mortality [1], [2]. Conventional risk factor assessments, such as blood pressure, cholesterol, lifestyle, pulse wave velocity, etc., can diagnose major CVDs like ischemia and arterial dysfunctions [3], [4]. The early prediction of structural dysfunctions such as valvular disorders, pericardial defects, and pulmonary arterial hypertension is challenging owing to the measurement complexity. The clinical standard technique to assess these

structural anomalies is central venous line catheterization, which measures the right atrial pressure changes [5].

The internal jugular venous pulses reflect the right atrial pressures, providing valuable insights into right heart dynamics [6], [7]. The JVP has six important fiduciary points, three peaks (a, c, v), and three valleys (x, x', y), respectively [6]. The ascents and descents in the JVP waveform represent the pressure changes in the right atrium during the cardiac cycle. The morphological abnormalities in the JVP waveform, such as their absence, amplitude, and location of fiduciary markers, can signify underlying cardiac anomalies like atrial fibrillation, tricuspid stenosis, septal defects, pericardial dysfunctions, hypovolemia, etc., and assist as a non-invasive vascular screening tool [6]. Hence assessing the pulse contour markers of the JVP can help in early detection of the occurrence of cardiac anomalies.

Despite its clinical significance, JVP acquisition and quantification are rarely performed in clinical examinations. Owing to the need for invasive surgical procedures and associated complexities, the standard central venous line catheterization is only employed in critical care settings for acute CVD patients. The widely used non-invasive technique is ultrasonography, where the JVP signals are captured either by tracking the JV wall motion or blood flow pattern [8]. Even though high-quality JVP signals can be acquired using this technique, it demands a trained operator for reliable measurements and is limited to short-term measurements. Other approaches based on PPG and optical sensors rely on measuring the skin displacements caused by the blood volume changes in the JV [9] - [12]. However, these systems demand postural restrictions and hence are unsuitable for longer signal acquisition intervals or for ambulatory monitoring.

In this pilot study, we have investigated the feasibility of extracting JVP using a contact piezoelectric sensor, potentially introducing a novel technique for JVP assessment. The JVP signals were captured using the piezoelectric sensor and digitized using the data acquisition hardware (PowerLab). The proposed measurement approach can acquire reliable JVP signals without sophisticated devices, postural constraints, or operator dependencies. An in vivo cohort study was conducted on 20 participants, demonstrating the feasibility of JVP measurement. The JVP signals acquired using the proposed approach were verified against those obtained from the reference A-mode ultrasound system. The JVP acquisition system, study details, and data collection strategy are elaborated in section II followed by the results and discussion

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in section III. The paper is then concluded by discussing the advantages and limitations of the proposed technique.

## II. MATERIALS AND METHODS

### A. Measurement System Architecture

The measurement system uses a piezoelectric sensor (TN1012/ST, AD Instruments, United States) connected to a data acquisition system (PowerLab C, AD Instruments, United States). The JVP signals were captured using the Labchart acquisition software at a sampling rate of 4000 Hz. The JV pulse was identified by visual examination of the participant's neck, and the piezoelectric pulse sensor was wrapped around the neck using a medical-grade hook-and-loop fastener with a velcro strap. The acquired signals were recorded as Labchart files and were further post-processed using algorithms developed in the LabVIEW (National Instruments Co., United States) platform.

### B. Signal Processing

The piezoelectric sensor captures the skin vibrations in neck resulting from the right atrial pressure changes [7]. Since the piezoelectric sensors are sensitive to changes in mechanical vibrations, the acquired signals represent the rate of change of the actual jugular venous pulses, represented as the first derivative JVP (D-JVP). The obtained signals were processed offline and integrated with respect to time to obtain the actual JVP signals (JVP). The baseline drift in the integrated signal was compensated by subtracting the linear trend estimated from the slope variation. The baseline corrected signal was further filtered using a second-order digital band-pass Butterworth filter (pass-band range: 1 to 10 Hz).

Beat-to-beat JVP cycles were selected from the filtered signal using an automated cycle segmentation algorithm [13]. A typical JVP cycle pattern comprises of six pulse contour markers, namely a, x, c, x', v, and y. A dedicated pulse contour algorithm was developed to identify the amplitude and location of all the markers.

The reference JVP signals were captured using an A-mode ultrasound system comprising of a 10 MHz transducer (5mm diameter) [14]. The reference system captures high-fidelity JVP signals at a frame rate of 250 Hz. The JVP signal acquisition and processing were performed on the LabVIEW platform. Pulse contour markers for beat-to-beat JVP cycles were evaluated using the fiduciary point identification algorithm. Fig.1 indicates the JVP measurement procedure.

### C. Verification Study Objectives

The pilot study was designed to:

- Evaluate the feasibility of JVP acquisition using contact measurement
- Verify the functionality of measurement by locating the pulse contour markers of JVP
- Compare and contrast the measurement accuracy against the reference A-mode ultrasound approach

### D. Study Protocol

The designed pilot study was conducted on a cohort of 20 healthy volunteers aged between 20 and 35 years. None of the recruited subjects had any history of venous or CVD

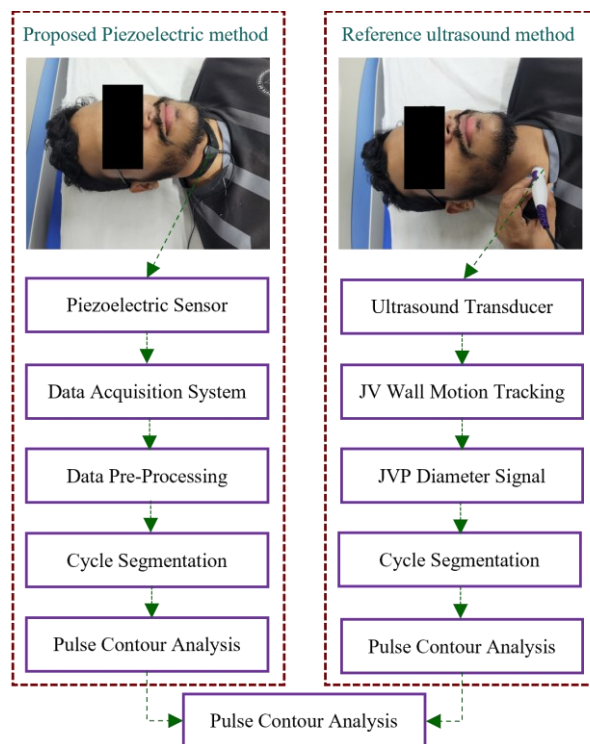


Fig. 1. Jugular Venous Pulse acquisition systems of the proposed piezoelectric and reference ultrasound methods

anomalies. All the in-vivo measurements were conducted in accordance with the guidelines and regulations approved by the Institutional Ethical Committee, IIT Madras (compliant with the Helsinki Declaration 1975, revised in 2013). The subject demographic details are indicated in Table I.

Participant information, including demographic details, lifestyle, and medical history were collected with a standardized questionnaire. The participant was advised to rest in a supine posture for a duration of 5 minutes. Oscillometric blood pressure measurements (SunTech®247™, SunTech Medical, Halma, UK) were recorded once the participant was relaxed. The right internal JV was selected for JVP measurement as it is directly connected to the right atrium. The piezoelectric sensor was placed over the internal jugular vein and was wrapped around the neck using a velcro strap. Care was taken to ensure minimal contact pressure (contact pressure < 6 mm Hg) on the JV to prevent flattening of the vein. The first derivative JVP signal output from the

TABLE I. SUBJECT DEMOGRAPHICS

Parameter	Range (Mean ± SD)
No of Participants (Male/ Female)	20 (10/10)
Age	20-35
Height (cm)	165.09 ± 8.24
Weight (Kg)	59.68 ± 13.27
BMI	21.80 ± 3.60
Brachial SBP (mmHg)	110.09 ± 8.63
Brachial DBP (mmHg)	79.31 ± 4.91
Mean Arterial Pressure (mmHg)	81.36 ± 14.74
Heart Rate (BPM)	79.31 ± 5.94

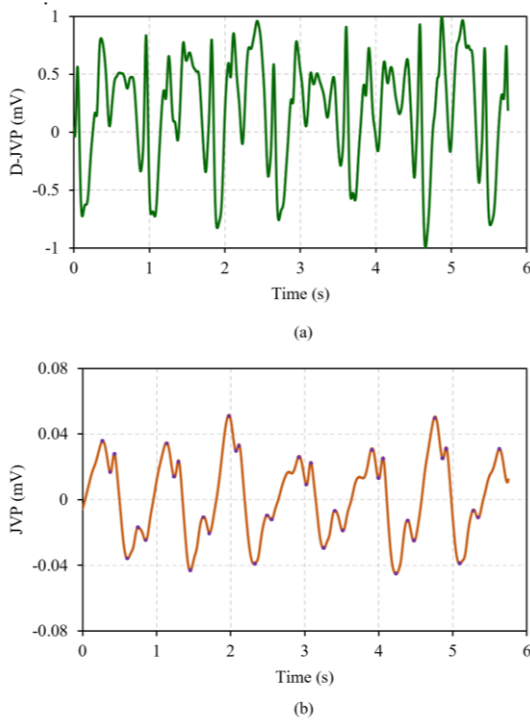


Fig. 2. (a) The skin displacements measured by the piezoelectric sensor (D-JVP) (b) Actual JVP from the integral of the D-JVP signal

piezoelectric sensor was recorded as Labchart files and was processed further to identify the JVP pulse contour markers. The reference JVP cycles were monitored using an A-mode ultrasound system [14]. Synchronous JVP signals were captured using both the piezo sensor and A-mode ultrasound system for a period of 2 minutes.

### E. Statistical Analysis

Population characteristics and measurement variables are represented as mean  $\pm$  standard deviation (SD) format. To demonstrate and compare the similarities and differences in pulse contour marker amplitudes and time instances, box-and-whisker plots were constructed. The beat-to-beat repeatability in measurements was quantified in terms of the coefficient of variation (represented as the % CoV) for 10 continuous JVP cycles.

## III. RESULTS AND DISCUSSION

### A. Reliability of Piezoelectric Data Collection

The piezoelectric contact measurement system could acquire JVP signals from all participants in the cohort. The acquisition system operates at a sampling rate of 4000 Hz, providing a higher resolution of 0.25 ms. Fig. 2(a) indicates the direct output from the piezo sensor (D-JVP) representing the jugular venous skin displacements, and Fig 2(b) indicates the baseline corrected JVP signals obtained by integrating the acquired signal (JVP). The cycle segmentation algorithm could segment the beat-to-beat JVP cycles with a specificity and sensitivity greater than 91 %. The good quality cycle selection enabled reliable beat-to-beat JVP pulses for pulse contour analysis. The pulse contour analysis was performed on the beat-to-beat cycles, and the average variation in the fiduciary point locations was found to be 17%. The identified

pulse contour markers of the acquired cycles are highlighted as shown in Fig. 2 (b).

### B. Reliability of Reference Data Collection

The reference JVP signals were acquired using an A-mode ultrasound system [14]. The measurement system operates at a frame rate of 250 Hz, ensuring a temporal resolution of 4 ms. High-fidelity JVP waveforms were acquired from the reference system owing to the quality of the echo frames (SNR > 20 dB). A real-time low frame rate distension waveform served as the visual feedback to the operator. The beat-to-beat variability in JV diameter measurements was found to be less than 6 %. The JVP diameter waveforms were analyzed using cycle segmentation and fiduciary point identification algorithms to yield the beat-to-beat JVP cycles and the pulse contour markers.

### C. Comparison against Reference A-mode Ultrasound

To evaluate the accuracy of JVP measurement, the JVP cycles acquired using the contact piezoelectric sensor were compared against the corresponding cycles captured by the A-mode ultrasound system. The beat-to-beat pulse contour marker locations measured using both modalities were analyzed. Fig. 3(a) indicates time instants of the occurrence of the peaks of the JVP cycle, while Fig. 3(b) represents the locations of the descents within a JVP cycle. Fig. 4 (a) indicates the correlation between the cycles measured using the two modalities in the cohort and Fig. 4(b) depicts the overplot of JVP measured using the proposed and reference methods. The JVP signals measured by the two approaches revealed a mean correlation of 0.90 and an RMSE smaller than 0.35.

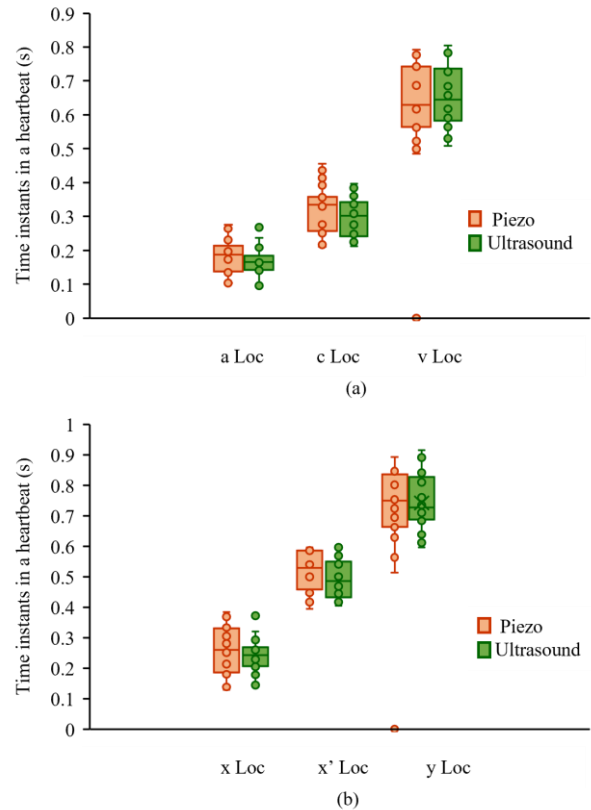


Fig. 3. Box-Whisker comparison plots indicating locations of JVP (a) ascents a, c and v (b) descents x, x' and y measured using the proposed piezoelectric sensor and the reference ultrasound sensor

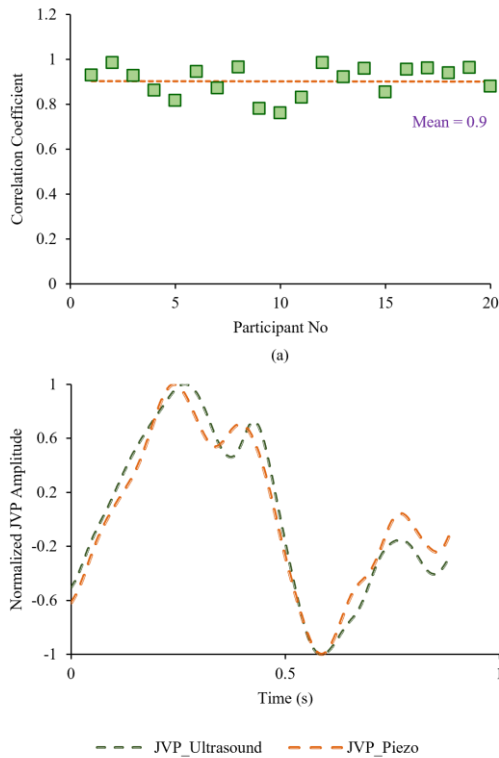


Fig. 4. (a) Correlation coefficient between JVP cycles measured using contact piezo sensor against A-mode ultrasound system (b) Overplot of JVP cycles measured using proposed and reference methods

#### D. Contact Pressure Assessment

For reliable JVP acquisition, it is essential to maintain minimal hold-on pressure. A higher contact pressure between the sensor and the skin can cause flattening of the JV, thereby creating erroneous results. To evaluate the contact pressure of the sensor, we used a catheter pressure sensor (Miller Instruments) attached to the neck of the subject by visual identification of the JVP pulsations. The pressure catheter readings for 10 consecutive cycles were recorded. Further, the piezo sensor was wrapped using the hook-and-loop fastener, and the catheter pressures were recorded. The mean baseline pressure was observed to be 5.21 mm Hg while the mean pressure with the sensor wrapped was 10.19 mm Hg. Fig. 5 demonstrates the pressure variations captured by the pressure catheter during baseline and with piezo sensor conditions.

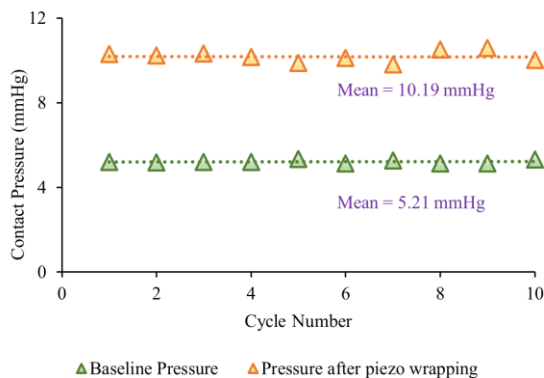


Fig. 5. Contact pressure measurement of the piezoelectric sensor over 10 cardiac cycles

#### E. Limitations

The piezoelectric contact sensor-based JVP measurement was conducted on a limited cohort involving 20 healthy participants. Since the morphology of the JVP pulse varies in various cardiac anomaly conditions [5], it is vital to validate the device's performance in the diseased population and against other vascular markers [15]. The current approach requires placing the sensor on the participant's neck, imparting contact pressure. An improved prototype that eliminates the hold-on pressure can considerably enhance measurement accuracy. More clinical trials involving various postural and intervention conditions are necessary to evaluate the sensitivity of the system.

#### IV. CONCLUSION

In this work, we have presented a novel approach for jugular venous pulse assessment. The proposed JVP measurement system consists of a simple piezoelectric sensor and a data acquisition system allowing it to be readily amenable in resource-constrained settings. As the sensor is positioned using a hook-and-loop fastener, it eliminates operator dependency and can be used for ambulatory monitoring for longer intervals without postural restrictions. The proposed technique was validated against an A-mode ultrasound system, and promising results were obtained. Further studies are underway to verify and validate the proposed method on a larger cohort and evaluate the clinical usability in different age groups and diseased populations.

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