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Evaluasi Kualitas Sinyal PPG dari Samsung Galaxy Watch5 Terhadap Perangkat Polar H10 Sebagai Reference-Grade
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INTISARI

Pemantauan stres mental secara kontinu menggunakan perangkat *wearable* berbasis *Photoplethysmogram* (PPG) masih menghadapi tantangan terkait validitas sinyal pada kondisi fisiologis yang dinamis. Aktivasi sistem saraf simpatis selama stres mental memicu vasokonstriksi perifer dan perubahan *Pulse Transit Time* (PTT) yang dapat memengaruhi amplitudo serta morfologi sinyal PPG di pergelangan tangan. Kondisi ini menimbulkan pertanyaan mengenai keandalan metrik *Pulse Rate Variability* (PRV) sebagai substitusi dari *Heart Rate Variability* (HRV) yang diukur menggunakan *Electrocardiogram* (ECG) sebagai standar emas. Penelitian ini bertujuan untuk mengevaluasi kualitas dan validitas sinyal PPG mentah dari perangkat konsumen Samsung Galaxy Watch 5 terhadap perangkat *reference-grade* ECG Polar H10 pada kondisi relaksasi dan stres mental, serta mengevaluasi efektivitas *pipeline* praproses dalam meningkatkan kelayakan sinyal untuk analisis HRV.

Penelitian observasional dilakukan terhadap 31 partisipan pria sehat menggunakan protokol terkontrol berdurasi 10 menit yang terdiri atas 5 menit fase relaksasi menggunakan teknik *box breathing* dan 5 menit fase induksi stres mental menggunakan kombinasi *Trier Mental Challenge Test* (TMCT) dan *Stroop Color-Word Test* (SCWT) secara serial. Sinyal mentah diproses menggunakan *pipeline* yang meliputi *bandpass filtering* (0,5–4 Hz), *Motion Artifact Detection and Correction* (MADC), *Signal Quality Assessment* (SQA) multi-indikator, serta *upsampling* dari 25 Hz menjadi 100 Hz. Validasi enam parameter HRV dilakukan secara terpisah pada kondisi relaksasi dan stres menggunakan analisis Korelasi Pearson, *Intraclass Correlation Coefficient* (ICC(2,1)), *Mean Absolute Error* (MAE), dan analisis Bland–Altman.

Hasil penelitian menunjukkan adanya pola degradasi performa yang sistematis pada pengukuran berbasis PPG selama kondisi stres mental. Pada kondisi relaksasi, seluruh parameter HRV menunjukkan tingkat kesepakatan absolut kategori *Excellent* dengan nilai ICC sebesar 0,930–0,995. Namun, pada kondisi stres terjadi penurunan performa pada seluruh parameter. Rasio LF/HF mengalami degradasi terbesar dengan nilai MAE mencapai 13,1

Sinyal PPG dari Samsung Galaxy Watch 5 menunjukkan kesesuaian yang sangat baik terhadap ECG pada kondisi relaksasi, namun mengalami penurunan akurasi selama aktivasi sistem saraf simpatis akibat stres mental. Penggunaan PPG untuk analisis HRV pada kondisi stres lebih sesuai apabila dibatasi pada parameter yang terbukti robust, seperti SDNN, serta disertai penerapan *Signal Quality Assessment* yang ketat. Hasil penelitian ini menunjukkan pentingnya pengembangan metode yang tidak hanya mengoreksi artefak gerakan, tetapi juga mampu mengompensasi perubahan fisiologis yang memengaruhi karakteristik sinyal PPG selama stres mental.

Kata kunci: *Photoplethysmogram*, *Heart Rate Variability*, stres mental, *wearable*, *Signal Quality Assessment*, Samsung Galaxy Watch 5.

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ABSTRACT

Continuous mental stress monitoring using wearable devices based on *Photoplethysmography* (PPG) remains challenging due to signal validity issues under dynamic physiological conditions. Activation of the sympathetic nervous system during mental stress induces peripheral vasoconstriction and changes in *Pulse Transit Time* (PTT), which can alter the amplitude and morphology of wrist-worn PPG signals. These physiological changes raise concerns regarding the reliability of *Pulse Rate Variability* (PRV) as a surrogate for *Heart Rate Variability* (HRV), which is conventionally derived from *Electrocardiography* (ECG) and regarded as the clinical reference-grade. This study aimed to evaluate the quality and validity of raw PPG signals acquired from the consumer-grade Samsung Galaxy Watch 5 against reference-grade ECG measurements obtained from the Polar H10 under both relaxation and mental stress conditions. In addition, the effectiveness of a signal preprocessing pipeline in improving signal suitability for HRV analysis was investigated.

An observational study was conducted involving 31 healthy male participants using a controlled 10-minute protocol consisting of a 5-minute relaxation phase employing a *box breathing* technique and a 5-minute mental stress induction phase combining the *Trier Mental Challenge Test* (TMCT) and the *Stroop Color-Word Test* (SCWT) in a serial manner. Raw signals were processed through a pipeline comprising bandpass filtering (0.5–4 Hz), *Motion Artifact Detection and Correction* (MADC), multi-indicator *Signal Quality Assessment* (SQA), and upsampling from 25 Hz to 100 Hz. Six HRV parameters were independently validated under relaxation and stress conditions using Pearson correlation analysis, *Intraclass Correlation Coefficient* (ICC(2,1)), *Mean Absolute Error* (MAE), and Bland–Altman analysis.

The results revealed a systematic degradation pattern in PPG-based measurements during mental stress. Under relaxation conditions, all HRV parameters demonstrated *Excellent* absolute agreement, with ICC values ranging from 0.930 to 0.995. However, performance deteriorated across all parameters during stress exposure. The LF/HF ratio exhibited the greatest degradation, with MAE increasing to 13.1

The PPG signal acquired from the Samsung Galaxy Watch 5 demonstrated excellent agreement with ECG-derived HRV measurements during relaxation but showed reduced accuracy during sympathetic activation induced by mental stress. The use of PPG for HRV analysis under stress conditions is therefore more appropriate when restricted to robust parameters such as SDNN and accompanied by stringent *Signal Quality Assessment*. These findings highlight the importance of developing future methods that not only correct motion artifacts but also compensate for physiological distortions affecting PPG signals during mental stress.

Keywords: *Photoplethysmography*, *Heart Rate Variability*, mental stress, wearable devices, *Signal Quality Assessment*, Samsung Galaxy Watch 5.