Accuracy and Signal Fidelity of a Low-Cost ECG Device: A Feasibility Study

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Abstract

Low-cost single-lead ECG recorders may help people capture rhythm symptoms outside the clinic, but the signal must still be good enough for ECG measurements. We compared a prototype recorder with a clinical 12-lead reference system in 22 adult volunteers, giving 23 paired 30-s recordings. The recordings were taken at rest, aligned in MATLAB by matched R peaks, and assessed for waveform shape, fiducial timing, interval and amplitude agreement, and beat classification. Across 528 pooled beats, morphology was generally close to the reference: mean correlation coefficient (CC) was 0.950 +/- 0.110, median CC was 0.982, and median dynamic time warping (DTW) distance was 0.00191. R-peak and QRS-onset timing were the strongest measurements, with mean absolute errors of 9.04 and 9.59 ms. Heart-rate bias was +0.059 beats/min and QRS-duration bias was +0.030 ms. Beat classification gave 97.0% raw accuracy, but Cohen's kappa was 0.482 and ventricular ectopic sensitivity was 70.8%. QT/QTc and amplitude measurements had wider agreement limits. These data support use for heart rate, QRS timing, and visual rhythm review in controlled recordings, but not standalone diagnosis.

1. Introduction

Many rhythm symptoms happen away from a clinic or a scheduled ECG appointment [1]. A low-cost home ECG recorder could therefore be useful if it captures a readable trace. The key question is simple: does the low-cost signal preserve enough timing and waveform shape to be interpreted alongside a clinical ECG?

Previous studies have shown useful performance from single-lead and reduced-lead devices for heart rate, atrial fibrillation detection, and QT/QTc measurement [2-5]. Most of that evidence comes from commercial devices. Reduced-lead recordings can also be weaker for voltage-dependent or morphology-dependent diagnoses [6]. A prototype recorder therefore needs more than a heart-rate check; it needs waveform, timing, interval, amplitude, and classification checks.

Here, a prototype low-cost recorder was tested against a clinical reference during simultaneous volunteer recordings. The aim was to see where the signal was already usable, and where more engineering or clinical testing was still needed.

2. Methods

Twenty-two adult volunteers without known heart disease were recruited after University of Leicester ethical approval and informed consent. Participants sat quietly for at least five minutes before recording. A supervisor placed the electrodes to keep lead position as consistent as possible. Each test included a 30-s clinical ECG recording and a simultaneous low-cost single-lead prototype recording. Files were stored under anonymized test identifiers.

Reference and prototype traces were exported as comma-separated values. MATLAB processing identified R peaks and aligned matching beats between systems. Signal quality was judged by whether the PQRST complex could be read visually and was not dominated by artefact. Because this was done by one rater, the judgement was treated as a feasibility check rather than a clinical endpoint.

Waveform shape was measured with Pearson CC, DTW distance, normalized mean square error (NMSE), and root mean square error (RMSE). Fiducial timing was assessed for the R peak, P onset, QRS onset, and T end using MAE, bias, and 95% limits of agreement (LoA). Beat classification was summarized for Normal, supraventricular ectopic (SVE), ventricular ectopic, and Noise classes. Heart-rate, interval, and amplitude agreement were summarized with Bland-Altman bias and LoA.

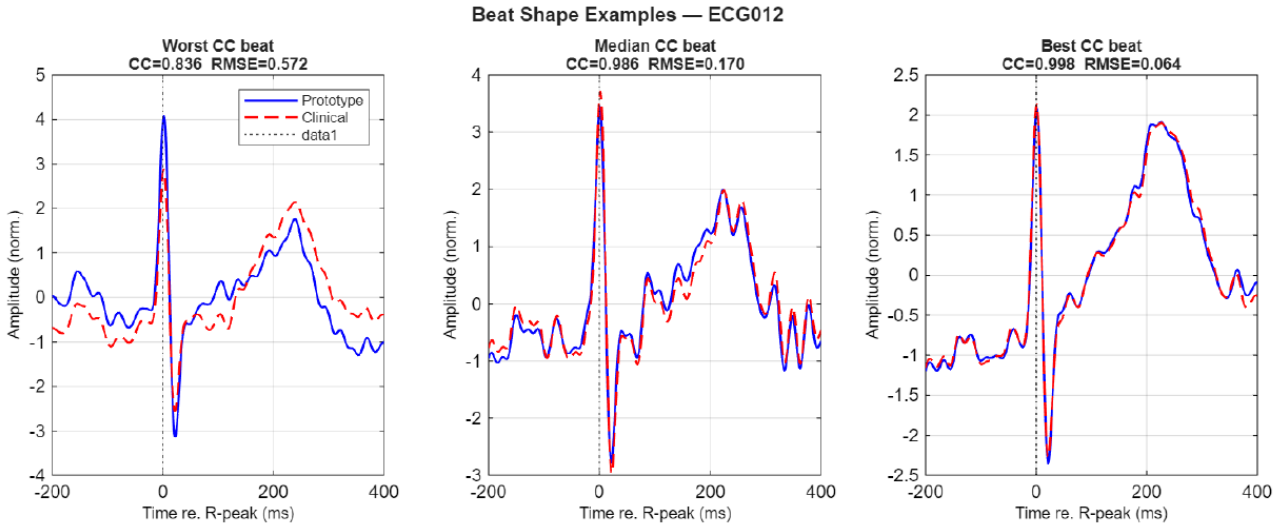

Figure 1. Example beats from ECG012: worst, median, and best correlation coefficient (CC) beats.

3. Results

Figure 1 shows three example beats from one paired recording. The worst, median, and best CC beats show the range seen in the data: some beats differed around the ST-T segment, while others matched the clinical trace closely.

Across 528 pooled beats, waveform shape was generally close to the reference. Mean CC was 0.950 +/- 0.110 and median CC was 0.982 (IQR 0.027). DTW distance was low (median 0.00191; mean 0.00277 +/- 0.00271). NMSE (mean 0.100 +/- 0.220; median 0.035) and RMSE (mean 0.248 +/- 0.196 mV; median 0.118 mV) were more variable, showing that a smaller group of beats accounted for much of the error.

Timing accuracy depended on the fiducial point. R-peak error was lowest (MAE 9.04 ms; bias -0.03 ms; LoA -42.6 to +42.6 ms), and QRS onset was similar (MAE 9.59 ms; bias -0.26 ms; LoA +/-43.5 ms). P onset and T end were less accurate, with MAE 28.5 and 20.0 ms. This gave good heart-rate and QRS-duration agreement, but wider PR and QT/QTc agreement limits (Table 1 and Figure 3).

Beat classification reached 97.0% overall accuracy (Figure 2). Cohen's kappa was lower at 0.482 because most beats were Normal. Normal beats had 99.1% sensitivity and 95.5% specificity. SVE and ventricular ectopic sensitivities were 80.1% and 70.8%. The Noise class could not be fully tested because there were no labelled noise beats.

Table 1. Summary of prototype performance against the clinical reference system.

Domain	Main metric	Result	Interpretation
Morph.	CC / DTW	median CC 0.982; median DTW 0.00191	Most beats matched the reference; outliers drove the mean.
Fiducials	MAE	R peak 9.04 ms; QRS onset 9.59 ms; P onset 28.5 ms; T end 20.0 ms	R peak and QRS onset were strongest; P onset and T end were weaker.
Intervals	Bland-Altman	HR bias +0.059 beats/min; QRS bias +0.030 ms; QT bias +3.84 ms	Heart rate and QRS duration were close; QT/QTc needs caution.
Class.	Sensitivity / kappa	accuracy 97.0%; kappa 0.482; SVE 80.1%; ventricular 70.8%	Accuracy was high because Normal beats dominated.
Amplitude	Bias	S wave -75.8 uV; T wave +99.7 uV	Systematic bias points to calibration or filtering differences.

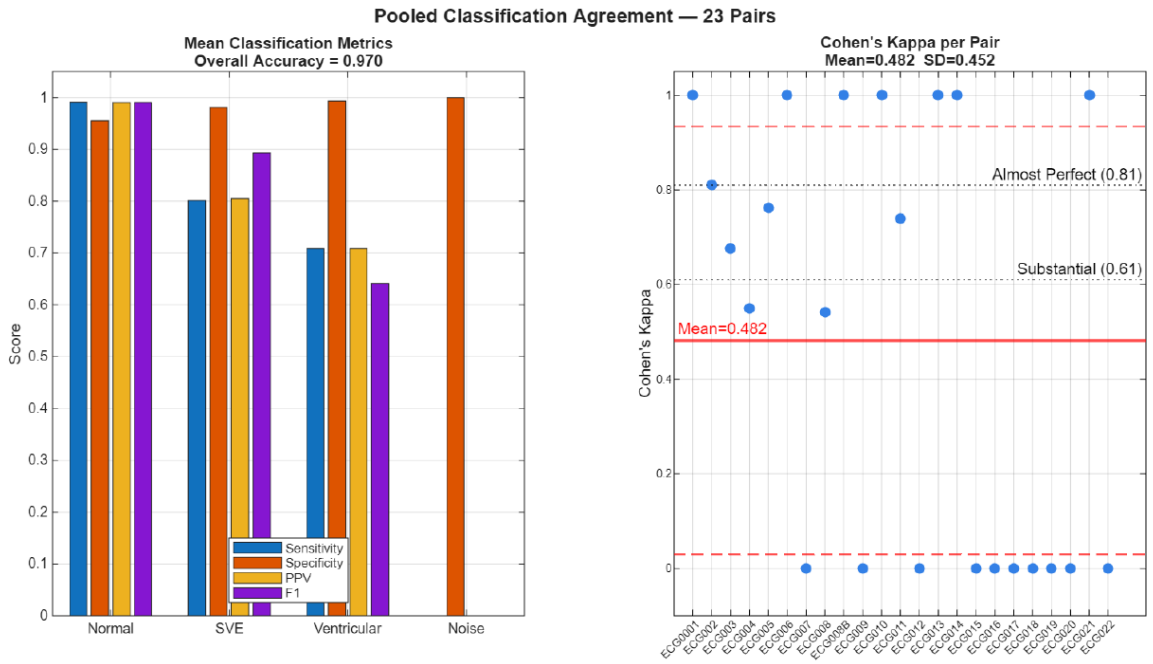

Figure 2. Classification metrics and Cohen's kappa. Raw accuracy was high, but kappa and minority-class sensitivity show limited readiness for autonomous arrhythmia detection.

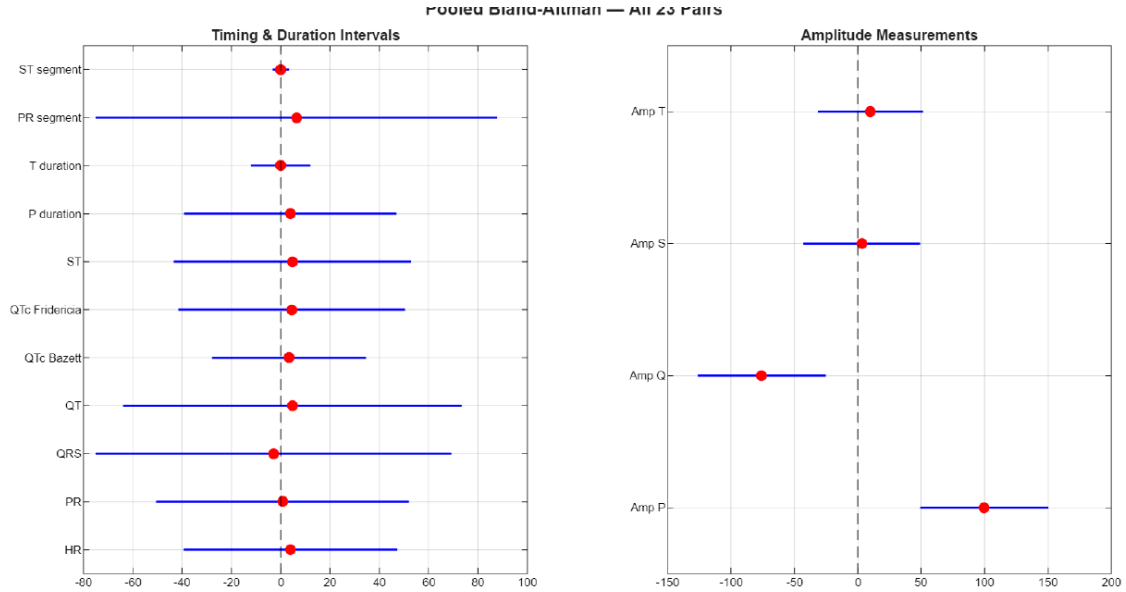

Figure 3. Bland-Altman summaries for intervals and amplitudes. Heart rate and QRS duration showed small bias, whereas S- and T-wave amplitudes showed systematic offsets.

4. Discussion

The prototype performed best for measurements based on the QRS complex. The waveform correlation, low DTW distance, R-peak MAE near 9 ms, and heart-rate bias below 0.1 beats/min support simple monitoring tasks such as heart-rate tracking and visual rhythm review.

The results also show the present limits of the device. P onset and T end were less reliable, which is expected because these features are smaller and less abrupt than the QRS complex [7]. That matters for PR, QT, and QTc measurement, where automated values often need manual checking before clinical use [8]. The S- and T-wave amplitude differences also look systematic rather than random, which is consistent with a filter or calibration mismatch [9,10].

The classification result needs caution. The high raw accuracy mainly reflects the large number of Normal beats. Kappa and minority-class sensitivity were weaker, especially for ectopic beats. Before the device is used for

automated arrhythmia monitoring, it should be tested on a balanced dataset with labelled noise, abnormal rhythms, and motion-contaminated recordings.

This was a controlled feasibility study. The recordings came from healthy adult volunteers, with supervised electrode placement, seated acquisition, and one-rater visual assessment. The results therefore support further development for low-risk monitoring, not replacement of a clinical ECG system.

5. Conclusion

In controlled paired recordings, the low-cost recorder preserved QRS timing and gave close heart-rate and QRS-duration agreement with the clinical reference. Atrial and repolarization fiducials, amplitude calibration, ectopic beat classification, and noise testing still need more work. At this stage, the device is best viewed as a possible screening aid, not a standalone diagnostic tool.

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