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Time Bias Awareness in ECG-Based Multiple Source Data Matching

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Abstract. For cardiological datasets acquired via different methodologies, ECG signals that are recorded in parallel allow for relatively accurate matching. Some research issues, e.g., the identification of timings of the cardiac cycle in seismocardiography, require higher temporal resolutions. Therefore, we introduce a method derived from a feasibility study to determine deviations and factors influencing the merging of signals simultaneously recorded with different modalities.

Keywords. analog-digital, synchronisation, seismocardiography, time delays

1. Introduction

The correlation of digital signals from different data sources for signal processing is difficult. It is even more challenging when dealing with systems with unknown specifications. In such cases, possible sources of influence need to be identified and quantified in order to be able to take corrective measures. In this paper, the authors present a method to help identify relevant temporal deviations [1] and influencing factors that bias the matching of ECG signal from different systems, namely echocardiography (ECHO) and seismocardiography (SCG) [2]. The knowledge of qualitative concepts and quantitative aspects affecting the measurement and interpretation of joint signalling is of great relevance. The method was developed with the following conditions in mind: it should be easy to reproduce, uncomplicated to use and it should not interfere with the hardware or software of the clinical device.

The experimental goals of this feasibility study comprise the determination of the sample rate for the two systems, the identification of a (qualitative) bias and how this bias is (quantifiably) associated with the image resolution and quantification of spatial deviations between collected ECG data from both systems.

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2. Method

The study was conducted on the 26.02.2022 at the Bielefeld University Hospital, Germany. A healthy volunteer was connected to the ECGs of the following two systems to provide for an adequate signal: GE™ Vivid™ E95 echocardiograph (General Electric Company, USA) with GE™ 4VC probe with 1.4/2.8 MHz, (system 1, ECHO), and an ECG-system using SHIELD-ECG-EMG, Rev.B, Olimex Ltd., Bulgaria (with a declaration of conformity according to the EMC Directive (2014/30/EU) and ROHS Directive) and FPGA (ICE40HX8) for recording purposes (system 2, SCG). The devices comprising system 2 were not pursuing a medical intent. The systems recorded four R to R (R-R) segments (five R peaks) simultaneously according to protocol: B-Mode with TVI with minimal[2]and maximal[3] frames per second (fps) resolution (FPS_{min}:50 fps and FPS_{max}:302 fps). A simultaneous joint mechanical cue on the ECG electrodes was used for synchronisation. For analysis, visual measurements of R-R distance were performed post-hoc using the Vivid™ E95 device on-board tool. Data recording and post-hoc computed measurements (peak analysis and distance measurements) were conducted with QtiPlot software, running on a laptop (Latitude 5310, Intel® Core™ i5-10310U CPU at 1.70GHz, 8GB RAM, Dell Corp., USA) with Ubuntu Linux (v. 20.04.4) that also recorded the data from the custom-made device. For statistical analysis, peak detection (first derivative method; in case of plateau measurement, the median was calculated) and data visualization were conducted with QtiPlot (version 1.0.0-rc17 (64-bit), Ion Vasilief). Descriptive statistical analysis was performed with standard functions of LibreOffice Calc (version 6.4.7.2, The Document Foundation), whereas inferential statistics (Wilcoxon-Test [3]) was carried out with SPSS (IBM® SPSS Statistics, v. 27.0.0.0, 64-Bit-Version, IBM® Corp).

The study was approved by the Ethics Committee of the Ärztekammer Westfalen-Lippe and WWU Münster, Münster, Germany, on the 15.02.2022 (2022-068-f-S; Chairman: Prof. Dr. W. E. Berdel).

3. Results

The authors identified a sample rate of 600 Hz used for ECG sampling of the ECHO by analysing the exported data from the TVI mode. The ECG of system 2 provided a constant sample rate of 1000 Hz. Accordingly, the variance, calculated as $\frac{1}{2 \cdot SR}$, was $0.8\overline{3}$ ms for the ECHO ECG and 0.5 ms per reading for the SCG ECG. Temporal deviations of the reference signal measured in the lower millisecond in the average 0 to 4.5 ms range could be detected in all modalities (B-Mode, M-Mode, TVI), resolutions (FPS_{min} and FPS_{max}), systems (1: ECHO and 2: SCG) and analysis methods (both visual and computational, Table 1). Comparing all deltas from the measurements of system 1 with lower frame rate (FPS_{min}) and higher frame rate (FPS_{max}) regardless of the modality, there was no statistically significant influence of the frame rate on the timely deviations seen descriptively (Wilcoxon-Test, two-sided, α: 0.05, β: 0.20, Z: −1.156, p: 0.248) (Table 2). When the deviations of the computed measurements from both systems were compared (TVI* and SCG) (Table 2)), the same was true (Wilcoxon-Test, two-sided, α: 0.05,

[2] depth: 2cm, width: 10°, comp.: 0, fq: 2.5 MHz

[3] depth: 30cm, width: 90°, comp.: 0, fq: 2.5 MHz

β: 0.20, Z: −1.841, p: 0.66), suggesting that the frame rate did not influence the time related deviations that were seen descriptively in a statistically significant manner. The overall time deviation between the two systems was 2.8±1.1 ms, with a range between 1.4 ms and 4.3 ms.

Table 1. RR intervals RR01 to RR04 in [ms] for each modality (BM: B-Mode, MM: M-Mode, TVI: TVI, *TVI: computed TVI, SCG) recorded with two frame rates (IR) for imaging FPS_{min} and FPS_{max}. The ECG sample rate (SR) of system 1 was 600 Hz, whereas that of system 2 was 1000 Hz. The IR marked * is the observed frame rate from the data.

	FPS_{min}					FPS_{max}				
[ms]	BM	MM	TVI	TVI*	SCG	BM	MM	TVI	TVI*	SCG
RR011	1039	1039	1043	1040	1047	1033	1033	1036	1038	1034
RR02	953	948	948	952	947	1073	1073	1066	1068	1068
RR03	999	999	1000	1000	997	1016	1016	1020	1018	1019
RR04	988	993	988	988	987	1039	1039	1035	1037	1037
IR [fps]:	50	17	50	*49.7	0	302	158	302	*301.8	0
SR [Hz]:	600	600	600	600	1000	600	600	600	600	1000

Table 2. Mean deviations of 4 R-R intervals in [ms] for each modality recorded with two image frame rates (values representing FPS_{min} are coloured in gray, while those for FPS_{max} are shown without highlighting). The average deviations are for FPS_{min} (2.8±1.1 ms) and FPS_{max} (2.8±1.4 ms). Statistically, there is no influence of the image frame rates.

	$m \pm SD$ [SD]	BM	MM	TVI	*TVI	FPS_{max} SCG
	BM		0.0 ± 0.0	4.5 ± 1.7	3.7 ± 1.6	2.8 ± 1.7
	MM	2.5±2.9		4.5 ± 0.5	3.7 ± 1.6	2.8 ± 1.7
	TVI	2.5±2.4	2.5±2.4		2.7 ± 0.4	1.8 ± 0.5
	*TVI	0.9±0.4	2.6±1.9	1.8±1.9		1.4 ± 1.9
FPS_{min}	SCG	4.3±3.3	4.3±3.3	2.3±1.5	4.0 ± 2.4	

4. Discussion

The protocol provided a feasible method to identify information about time deviations that could be considered as corrective measures for future attempts of signal mapping via ECG as the reference signal. In the current experiment, the detected deviations were overall small (m:2.8 ±1.1 ms). Nevertheless, for scientific experiments that require high precision, these could still be significant. An interpretation must also consider the consequences arising from the sampling theorem [4], as a sample rate dependent quantization variance may interfere with precision of the measurements. These variations are unavoidable but must be considered [5]in attempts of matching signals. In matching two signals with the same characteristics and recorded with an adequate (and comparable) sample rate, the time deviations are considered acceptable. In our experiment, the relevant quantization variance was 0.83 ms. The quantization variance is especially relevant for two signals recorded using different acquisition methodologies as well as sample rates. A prime example of this are two signals recorded simultaneously such as ECG representation (sample rate: 600Hz) and an exemplary ultrasound image dataset that is recorded with 50fps. The quantization variance is ± 10 ms, which is an accuracy mostly acceptable for clinical questions, but potentially problematic for precise scientific measurements like mapping signals with a frequency in that specific range (e.g., cardiac valve closure). Additional aspects interfering with the accuracy is the fact that there may be a delay between the registration of the ECG and ultrasound image onset that is described by Nadkarni et al. [6] Walker et al. [7]. This kind of information is not commonly provided by manufacturers of ultrasound machines used in cardiological contexts [7] and will be addressed in a follow-up experiment. The current feasibility study was conducted to explore a non-clinical method. It focused on neither diagnostic nor therapeutic impact, either for the participant or for the general public and it was neither invasive nor contained any inacceptable health risks nor was meant to deliver any data for future conformity assessments. Only one subject in one setting was needed to provide an adequate signal for recording purposes. We applied a descriptive design to receive initial input about the expected effects to be used for hypothesis generating purposes and study planning. Our aim was to determine in a qualitative manner whether - and if so, to what extent – there were any relevant differences between the measurements acquired using the different systems in our setup. The follow-up experiment will include improvements to the equipment [8] that will also affect the recorded samples for a quantitative analysis. We will address these issues in a follow up experiment. In the future, the setup will be improved. A high-quality signal generator will provide a well-defined signal with respect to the geometry and duration of the signal cycles. This adaptation will standardize the measurements and make them more comparable. Furthermore, it will be possible to measure the absolute latency of the onset of the first R wave. At the moment, only the relative onset could be defined. Also, the artificial signal will help to record a larger number of signal intervals, and this in turn will increase the sample size to be used for comparison. The bias of the visual analysis will be improved by including additional raters for the measurements and to calculate the interrater reliability.

5. Conclusions

The presented method seems to be helpful to identify relevant time-related aspects for future work regarding the matching the ECGs of the two systems. More research is necessary to learn about bias due to latency, offset and jitter.

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