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Interoperable Integration of Automatic ECG Processing Using DICOMweb and the AcuWave Software Suite

Lennart GRAF [a,1], Dagmar KREFTING [a,b], Tibor KESZTYÜS [a], Maximilian OREMEK [c,d], Sven ZENKER [c,d] and Nicolai SPICHER [a,b]
[a] *Dpt. of Medical Informatics, University Medical Center Göttingen, Germany*
[b] *DZHK (German Centre for Cardiovascular Research), Partner Site Göttingen, Göttingen, Germany*
[c] *Unit for Medical and Scientific Technology Development & Coordination, Coordination (MWTek), Commercial Directorate, University Hospital Bonn, University of Bonn, Bonn, Germany*
[d] *Applied Mathematical Physiology (AMP) Lab, Department of Anesthesiology & Intensive Care Medicine, University of Bonn Medical Center, Bonn, Germany*
ORCiD ID: Lennart Graf https://orcid.org/0009-0000-6059-9893,
Dagmar Krefting https://orcid.org/0000-0002-7238-5339,
Tibor Kesztyüs https://orcid.org/0000-0003-0813-2393,
Maximilian Oremek https://orcid.org/0000-0001-5959-7735,
Sven Zenker https://orcid.org/0000-0003-0774-0725,
Nicolai Spicher https://orcid.org/0000-0002-2879-9948

Abstract. Established cardiovascular risk scores are typically based on items from structured clinical data such as age, sex, or smoking status. Cardiovascular risk is also assessed from physiological measurements such as electrocardiography (ECG). Although ECGs are standard diagnostic tools in clinical care, they are scarcely integrated into clinical information systems. To overcome this roadblock, we propose the integration of an automatic workflow for ECG processing using the DICOMweb interface to transfer ECGs in a standardised way. We implemented the workflow using non-commercial software and tested it with about 150,000 resting ECGs acquired in a maximum-care hospital. We employed Orthanc as DICOM server and AcuWave as signal processing application and implemented a fully-automated workflow which reads the ECG data and computes heart rate-related parameters. The workflow is evaluated on off-the-shelf hardware and results in an average run time of approximately 40 ms for processing a single ECG.

Keywords. Clinical workflows, DICOM, DICOMweb, Electrocardiography

1. Introduction

Although ECG is widely used in clinical care due to its low risk and costs, the biosignal data are scarcely integrated into clinical workflows in a way that allows for straightforward integration of quantitative analytics beyond what is provided by the

[1] Corresponding Author: Lennart Graf; E-mail: frederiklennart.graf@med.uni-goettingen.de.

device vendor. Oftentimes, ECG printouts are used and only the diagnosis made by the cardiologist is stored in electronic healthcare records. Interoperable file formats and interfaces are rarely supported by vendors, impeding seamless integration into digital workflows [1].

The European data format (EDF) and Digital Imaging and Communications in Medicine (DICOM) [2] are two examples of open file formats for ECG data. While EDF is widely used as archiving format, DICOM is the de-facto standard in medical imaging and is increasingly specified also for biosignals to extend standard Picture Archiving and Communication Systems (PACS) to manage biosignal recordings [3]. ECG device vendors increasingly offer export in DICOM format. When imported to a common PACS, they can be easily transferred to connected systems for further processing, e.g. the AcuWave platform [4]. To address the issues identified, the ACRIBiS project is working towards digitising hospital ECG workflows. The objective of this paper is an interoperable integration of ECG data for automatic analytics workflows by developing a DICOMweb interface for the analytics platform.

2. Methods

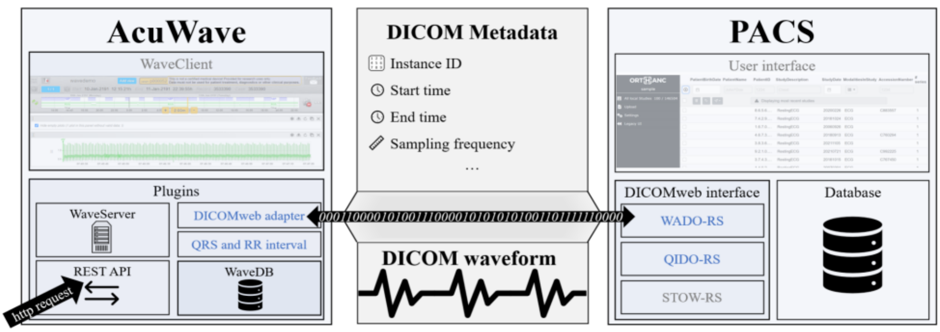


Figure 1. Automated ECG processing workflow with arrows indicating information exchange.

Fig. 1 depicts the system architecture: DICOM ECG data is stored on a lightweight PACS with a DICOMweb interface, namely Orthanc (v.1.12.1) [5-7]. ECG Data shall be processed on the AcuWave platform. It is written in Java and consists of four main components: A database for data storage, a modular server for data analysis, a web application as user interface, and a REST interface. External systems, e.g. cardiology information systems, can request results of ECG processing via the REST interface.

The intended use case is that an external system calls the REST endpoint of AcuWave with identifiers for a patient, the ECG recording, and the lead of interest (I-III, aVL-aVR, V1-V6). Then AcuWave i) requests the DICOM data from Orthanc via the DICOMweb adapter, ii) performs QRS detection and RR interval computation, and iii) returns RR intervals as response via REST to the requesting system.

2.1. AcuWave DICOMweb plugin

DICOMweb is a standardised REST-API for web-based image transactions, such as searching via QIDO-RS and retrieval via WADO-RS. We implemented a plugin for AcuWave which enables to send DICOMweb queries to respective endpoints:

1. *Connection module*: checks for valid connection to a PACS
2. *Object list module*: retrieves ECG metadata from the PACS via a QIDO-RS call
3. *Record list module*: filters the retrieved metadata and outputs a WADO-RS URL
4. *Data module*: retrieves ECG waveform data via the WADO-RS URL and processes it into the required waveform object structure in AcuWave.

To process the DICOMs and extract the actual waveform data in the *Data module*, we used PixelMed, an open-source Java library under BSD license [8].

2.2. AcuWave RR interval application

From a technical perspective, we combined the *Record list* and *Data module* introduced in 2.1 with a RR interval plugin which is already part of AcuWave and a modified Pan-Tompkins algorithms [9]. The end product of this application is a URL with a REST endpoint, which the user can query and which returns timestamps and RR intervals:

Request:

```
http://0.0.0.0:8082/data/ecgdicomdetector?recordkey=1&dicompat=1&
ecgchannel=1
```

Reply:

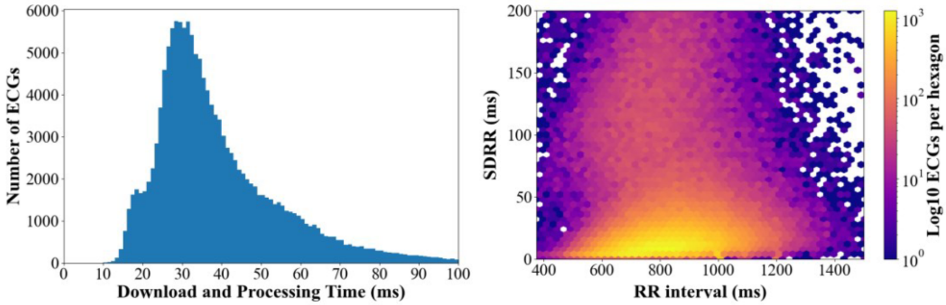

```
{"data":["x":"UNIX timestamp","y": "interval in [ms],
"x":1579160853001.786,"y":808.0, "x":1579160853002.594,"y":832.0,
"x":1579160853003.426,"y":842.0, "x":1579160853004.268,"y":938.0,
"x":1579160853005.206,"y":856.0, "x":1579160853006.062,"y":1030.0,
"x":1579160853007.092,"y":824.0]}
```


2.3. Evaluation

In order to evaluate the developed workflow, we focus only on processing and not on network transmission times. Hence, all software is run on a single off-the-shelf laptop (i7 11850H 2.5GHz, 32GB RAM). A Python script was implemented which calls the AcuWave REST endpoint and receives the result for each ECG as a JSON-formatted message. The script was written to process tasks simultaneously using 20 threads with the library ThreadPoolExecutor [10]. We measure the total time it takes to send the ECG data from Orthanc to AcuWave and to calculate RR intervals.

To download data from a DICOMweb server, it is necessary to know its Study ID, Series ID, and Instance ID. However, it is not possible to retrieve the number of ECGs available without all metadata on the DICOMweb server as no function for that exists within the standard. Hence, in order to have information about the ECGs available on the DICOMweb server, it is necessary to retrieve all the metadata of the ECGs in a first step and then sequentially build the download link with the Study ID, Series ID and Instance ID. Due to memory constraints, we cached the metadata of the QIDO-RS call made in the object list module and then divided them into manageable chunks.

The analysed data set consists of 146,504 resting ECGs recorded within the University Medical Center Göttingen during the periods 07/2006 - 02/2008 and 01/2018 - 11/2021. 12-lead ECG devices (SCHILLER AG, Baar, Switzerland) were used with a sampling rate of 500 Hz. Data was anonymised and provided by the Medical Data Integration Centre of the University Medical Center Göttingen without manual data curation.



(a) Distribution of ECG processing times. (b) RR interval vs. SDRR.

Figure 2. Results: To improve visualisation, 1.8% and 4.6% outliers are not shown in (a) and (b), respectively.

3. Results

146,399 ECGs were successfully processed by the pipeline. 105 ECGs were processed but the QRS detector was not able to determine any beats.

Fig. 2a shows a histogram with the distribution of the 146,399 runtimes in 1 ms steps. The median value of 34.95 ms is 13.79% lower than the mean value of 40.54 ms. This indicates that the runtimes above the median have a greater spread than those below the median. The minimum is 10.05 ms and the maximum is 395 ms. The standard deviation is 21.09 ms and is therefore 47.98% below the mean. The runtimes are therefore subject to fluctuations, which may be due to the simultaneous processing of the processes and occasional contention for hardware resources.

Fig. 2b displays a hexagonal binning plot of RR vs. SDRR values. Although 10s resting ECGs have only limited value for HRV analysis [11], we can see that the computed values follow a reasonable distribution with the majority of RR values being in the interval 600 −1000 ms.

4. Discussion and Conclusions

In this article, we proposed an automatic pipeline transferring ECGs in DICOM format from an open source DICOM server towards the AcuWave software suite for processing. As example analysis, RR and SDRR values were computed and yielded expected results. While resting ECGs – which are usually captured for 10 seconds only – have only limited value for HRV analysis [11], our rationale was to provide a bottom base-line analysis. Better algorithms, e.g. for extraction of clinically-relevant intervals [12] or decreased vagal activity [13] would only increase diagnostic value of the pipeline. For doing so, the integration of long-term ECGs will be essential.

In developing the pipeline, we encountered a challenge in retrieving the metadata (DICOM tags) of the instances from Orthanc. While DICOMweb allows for the retrieval of all metadata items of a specific instance via QIDO-RS, it does not allow for the retrieval of specific fields such as Study ID, Series ID, Instance ID, or even the WADO-RS URL. This results in extra effort to query the metadata, e.g. the study date (0008, 0020) was not in our interest for each retrieval of a single ECG. We resolved this issue by implementing caching, allowing us to utilise an index that does not require the Study

ID, Series ID and Instance ID for a query. In future work, we aim to deploy the proposed architecture using Docker containerisation to clinical infrastructure within the next year and store the results in a FAIR manner in a PACS. Another avenue for future work could be to combine the pipeline with validated neural networks or High Performance Computing (HPC) as in case of computationally-expensive methods and larger datasets this will be required at a certain point. First works have shown the feasibility of sending data in a secure workflow to a HPC cluster and retrieving the results [14].

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