Naturalistic measurement of multi-person cardiac activity using open source smartwatch technology

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Objectives

Measure cardiac activity from multiple participants in naturalistic environments

- Increase generalizability of findings in music psychology
- Increase replicability of large-scale multi-person studies
- Provide an accessible and user-friendly system that scales from the lab to the wild

Design goals

Develop a practical, accessible, and user-friendly system that can:

- Measure detailed cardiac activity from one to many (40+) participants
- Efficiently monitor participants and devices
- Build on open source hardware and software
- Verify capabilities of the system
- Produce documentation and tutorials detailing the uses and limitations of the system

The resulting system architecture is outlined in Figure 1.

Watch and participant setup

Each participant is fitted with a Bangle.js 2 smartwatch (Figure 2) that:

Figure 2. Bangle.js 2 watch running the *BEATwatch* application. Watches are easily attached to participants' wrists, record PPG data to internal storage, and transfer completed records via BLE.

- Measures blood pulse volume via PPG
- Displays recording status
- Connects via Low Energy Bluetooth (BLE) to a remote host computer
- [Optional] Manually starts recording data via touchscreen

System architecture diagram

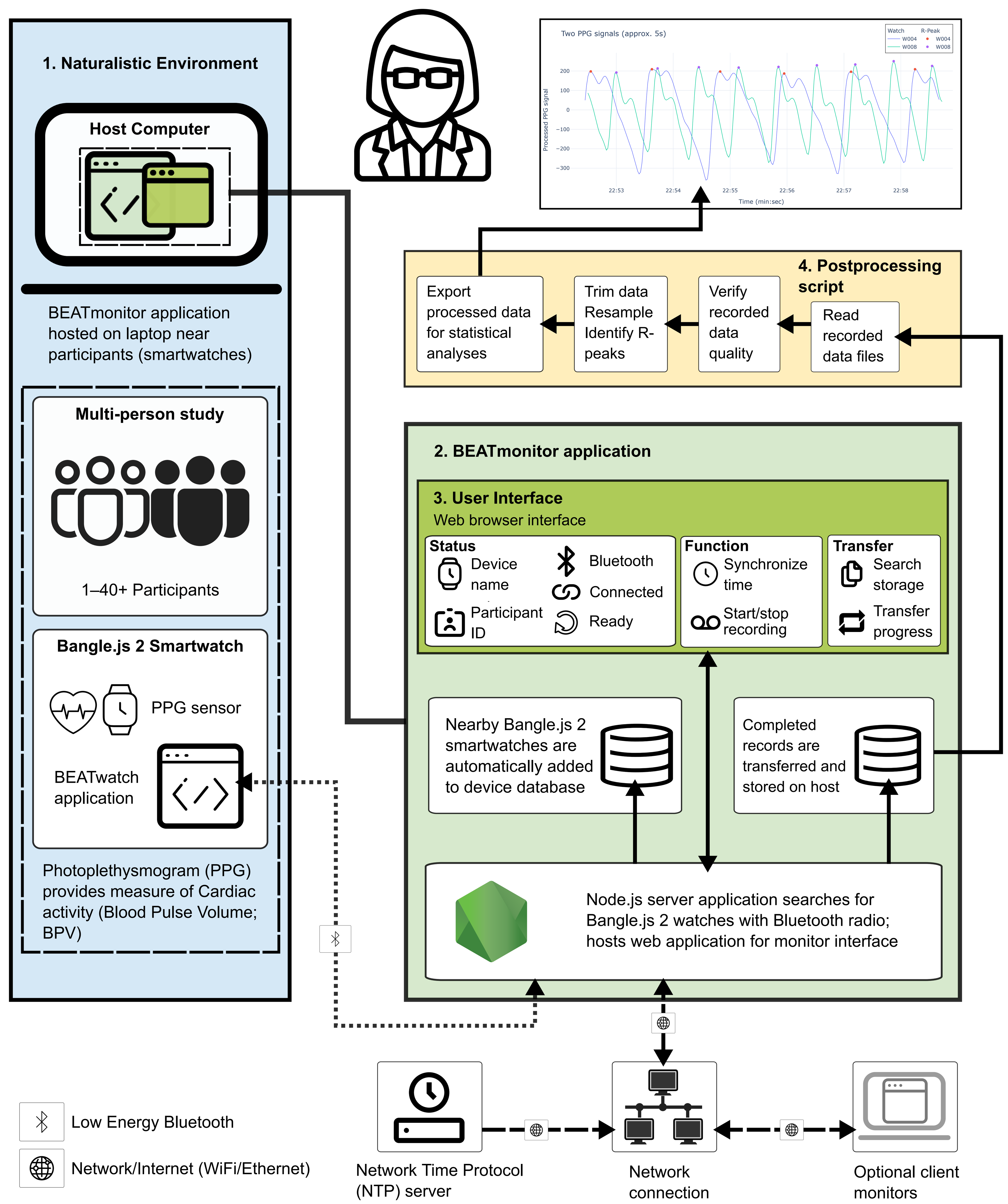

Figure 1. Components and processes of the system. The *(1) Naturalistic Environment* (the time and location of a study) contains a host computer (laptop), participants, and Bangle.js 2 smartwatches running the BEATwatch application. The host computer runs the *(2) BEATmonitor* server application, which searches for nearby watches over BLE, and is able to connect to perform time synchronization, recording, and file transfer operations. The *(3) User Interface* can be accessed by any network computer and displays the status of watches and activates watch functions. A *(4) Postprocessing Script* is included that performs basic data cleaning, verification, resampling, and R-peak detection[1] (used to calculate heart rate, heart rate variability, etc.) prior to exporting for final analyses.

BEATmonitor and user interface

The BEATmonitor server application runs on the host computer and:

- Searches for nearby watches via BLE
- Maintains a database of known devices
- Connects to, and sends/receives commands and data from single/multiple watches
- Maintains a database of transferred recordings from individual watches
- Serves a web interface (Figure 3; accessible on the host or network computer) that displays watch data and controls watch functions

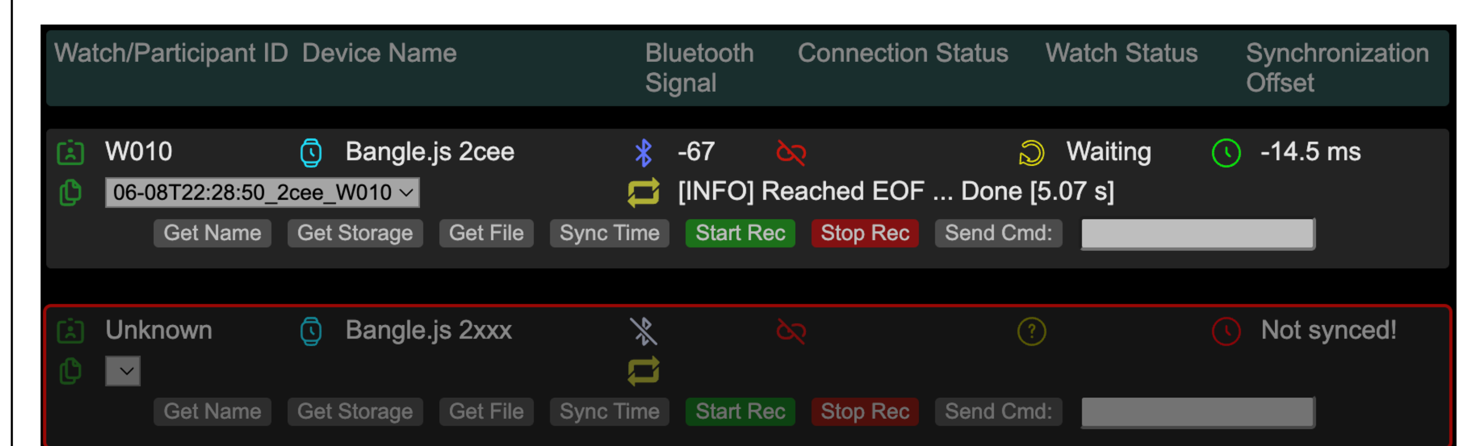

Figure 3. The user interface displays information for all detected and nearby watches. The Participant ID, Device name, BLE signal strength, and watch recording status are updated automatically. Watch time is synchronized with a common NTP server (enabling comparison with other study materials). Recording, storage transfer, and custom commands are sent via the interface buttons.

Outcomes

The system we have designed:

- Is easily attached and worn by participants who can then move freely and uninterrupted in natural listening environments
- Is versatile, accommodating from one to 40+ participants
- Records PPG and average heart rate at 25 Hz to internal watch storage for up to 3 hours
- Is well-timed (+/-30 ms) to stimuli presentation and other measurement instruments
- Is monitored and controlled remotely, decreasing the need for experimenter intervention
- Includes postprocessing scripts and tutorials to enable quick and accurate preparation for analyses
- Is well-documented and openly accessible (see QR code)

References: **[1]** Makowski, D., Pham, T., Lau, Z.J. et al. NeuroKit2: A Python toolbox for neurophysiological signal processing. Behav Res 53, 1689--1696 (2021). https://doi.org/10.3758/s13428-020-01516-y. **[2]** Icon files obtained from SVG Repo https://www.svgrepo.com.