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Undergraduate Students Compete in the IEEE Signal Processing Cup: Part 3

The IEEE Signal Processing (SP) Cup is a competition that provides undergraduate students with the opportunity to form teams and work together to solve a challenging and interesting real-world problem using signal processing techniques and methods.

The second IEEE SP Cup, held during the fall and winter of 2014, had the following topic: "Heart Rate Monitoring During Physical Exercise Using Wrist-Type Photoplethysmographic (PPG) Signals" [1]. Participating students were grouped in teams and provided with PPG signals recorded from subjects' wrists during physical exercise. Students were then asked to design an algorithm to estimate the subjects' corresponding heart rates.

BACKGROUND AND MOTIVATION

Wearable health monitoring is a popular, fast-growing area in both industry and academia. Numerous wearable devices for monitoring vital signs have been developed and sold or are selling on the consumer market, such as smart watches and smart wristbands. A key function of these wearable devices is heart rate monitoring using PPG signals recorded from users' wrists. This function can help users control the intensity of their workout according to their heart rate or, alternately, help remote health-care providers monitor the health status of the users.

However, estimating heart rate using wrist-type PPG signals during exercise is a difficult problem. The movements of the users, especially their wrist motion, can result in extremely strong motion artifacts (MAs) in recorded PPG signals, thereby seriously degrading heart rate estimation accuracy (Figure 1). Such interference calls for effective MA removal and heart rate estimation methods.

As a researcher with years of experience in PPG-based heart rate monitoring, I realized that this problem was suitable for the SP Cup for the following reasons:

- The problem can be formulated into a typical signal processing problem from different perspectives. For example, with the available simultaneous acceleration signals, it can be formulated into an adaptive noise cancellation problem. Alternatively, it can be formulated into a single-channel (or multichannel) signal decomposition problem. Therefore, students have the freedom to choose different signal processing techniques to solve this problem, based on their preferences and academic backgrounds.
- Solving this problem requires jointly using multiple signal processing algorithms, fostering collaboration between team members. A successful heart rate monitoring solution consists of many components, such as digital filtering, interference cancellation, power spectrum estimation, signal decomposition, or other advanced algorithms, depending on the kind of signal processing problems formulated by the students. Therefore, team members can divide the problem into a number of subproblems, working on them separately. But they also need to closely collaborate with each other to achieve the optimal performance of their whole solution.

As a result, I submitted a proposal to run an SP Cup on this topic last year, and I was delighted to learn that it had been accepted.

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DESCRIPTION OF THE COMPETITION

Approximately 270 students, consisting of 66 teams, registered for this edition of the SP Cup. They came from 21 countries/areas. Ultimately, 49 teams submitted their results by the deadline with qualified submission materials.

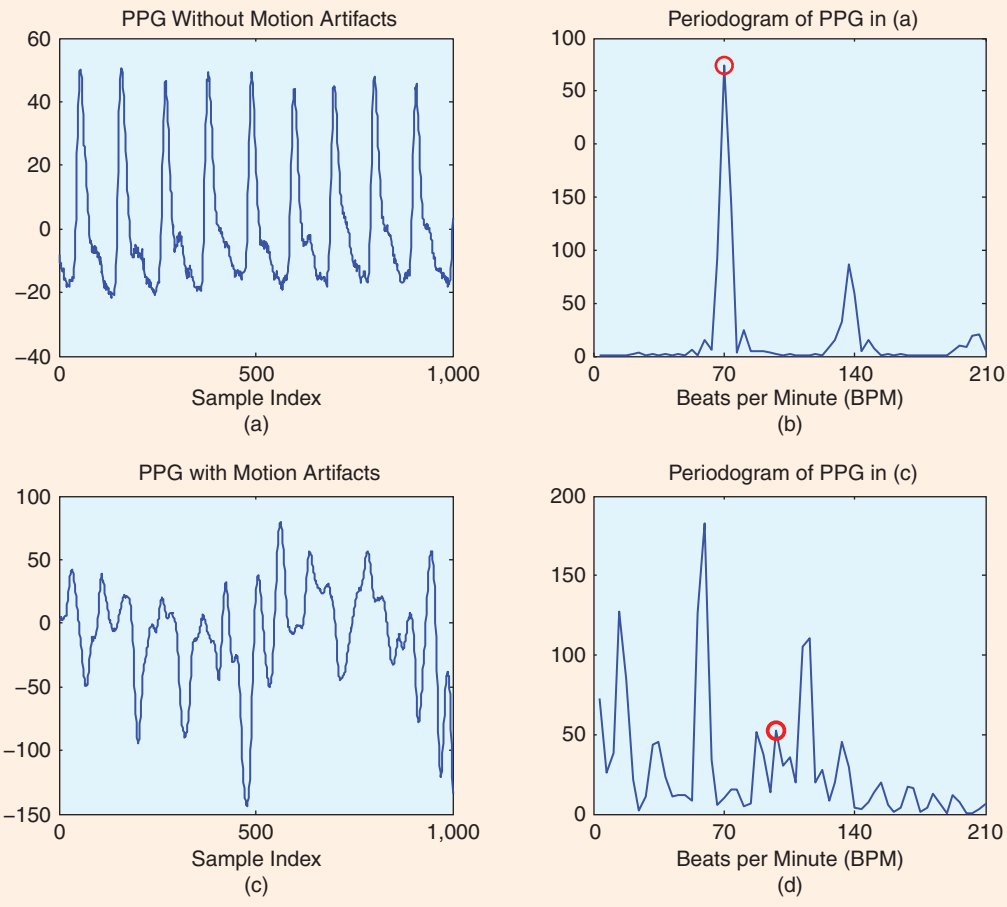
The competition had two rounds. In the first round, performance evaluation was mainly based on an average absolute estimation error, defined as the difference between true heart rates and estimated heart rates averaged over the whole test database. Three teams with the best estimation performance were selected to enter the final round. The finalist teams presented their work at ICASSP 2015. A panel of judges attended their presentations and ranked them. The evaluation criteria included 1) the average absolute estimation error (mean and variance), 2) the algorithm novelty, 3) the quality of the report writing, and 4) the oral presentation. Details of the competition procedure can be found in [1] and [3].

COMPETITION RESULTS

FIRST PLACE: SIGNAL PROCESSING CREW DARMSTADT

The team Signal Processing Crew Darmstadt (Alaa Alameer, Bastian Alt, Christian Sledz, Hauke Radtki, Maximilian Hüttenrauch, Patrick Wenzel, and Tim Schäck) from Technische Universität Darmstadt,

The IEEE SP Cup 2016 will be held at ICASSP 2016 with the competition topic: "Exploring Power Signatures for Location Forensics of Media Recordings." Visit http://www.signalprocessingsociety.org/community/sp-cup/ for more details.



[FIG1] A comparison between an MA-free PPG signal and an MA-contaminated PPG signal. (a)–(d) shows the MA-free PPG signal and its spectrum, and the MA-contaminated PPG signal and its spectrum, respectively. The spectra are calculated using the periodogram algorithm. The red circles in (b) and (d) indicate the spectral peaks corresponding to the heartbeat. The x-coordinates in (b) and (d) are expressed by BPM for convenience, instead of hertz. The comparison shows the difficulty of identifying heart rate from MA-contaminated PPG signals. (Figure adapted from [2].)

Germany, supervised by Dr.-Ing. Michael Muma, won first place. They adaptively estimated the time-varying transfer functions of each one of the tri-axis acceleration signals that produced artifacts in raw PPG signals. A quality-weighted combination of the outputs of the adaptive filters was then used to form a cleansed signal from which the heart rate was estimated. The method achieved the average absolute estimation error of 3.44 beats/minute (BPM) on the test database.

SECOND PLACE: SUPERSIGNAL

The team Supersignal (Sayeed Shafayet Chowdhury, Rakib Hyder, Anik Khan, Md. Samzid Bin Hafiz, and Zahid Hasan) from Bangladesh University of Engineering and Technology, Bangladesh, supervised by Prof. Mohammad Ariful Haque, took second place. This team proposed a solution, mainly based on adaptive filtering, with carefully designed reference signals from tri-axis accelerometer data and PPG signals.The team obtained the average absolute estimation error of 2.27 BPM on the test database.

THIRD PLACE: SSU

The team SSU (Gyehyun Baek, Minkyu Jung, Hyunil Kang, Jungsub Lee, Baeksan On, and Sunho Kim) from Soongsil University, South Korea, supervised by Prof. Sungbin Im, placed third. To remove motion artifacts in the raw PPG signals, the team proposed a solution based on a multiple-input, single-output (MISO) filter with tri-axis accelerometer data as inputs, where the MISO filter coefficients are estimated using the Wiener filter approach. The solution obtained the average absolute estimation error of 3.26 BPM on the test database.

Figure 2 shows the estimation results of the three teams on set 2 of the test database.

FEEDBACK FROM PARTICIPATING STUDENTS AND SUPERVISORS

I received extensive feedback from the participating students and their supervisors. Due to space constraints in this article, selected samples from the three winning teams are given next.

STUDENTS' FEEDBACK ON THE EXPERIENCE

I think the SP Cup is very helpful in a sense that one can work on close-to-real-world problems.The problem was not as designed as university tasks, and the data were collected from real experiments. Also, it showed that often not the most complex and sophisticated concepts lead to good results, but rather, one starts out with a basic idea and adds bits and pieces to this initial idea.

—Signal Processing Crew Darmstadt

We had to learn a lot of new topics like adaptive filtering, wavelet decomposition, empirical mode decomposition, singular spectrum analysis, etc. in an attempt to solve the problem. We think solving, or even attempting to solve, a real-life signal processing problem helps a lot to build up our interest, as well as understanding, in signal processing.

—Supersignal

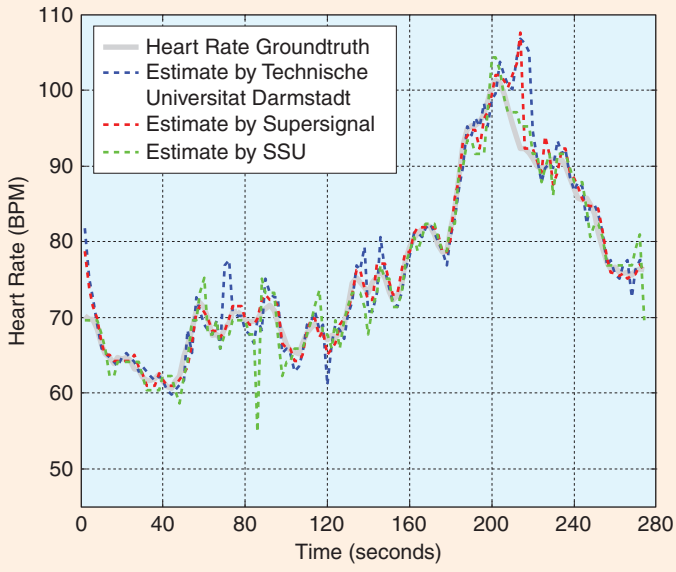
Our team members and I regularly met to study algorithms, including independent component analysis, singular spectrum analysis, sparse signal recovery, Kalman filter, and so on, during meetings. These techniques helped us deal with our goal. We tried to implement some of the techniques into MATLAB codes.

—SSU

STUDENTS' FEEDBACK ON TEAMWORK

Our SP Cup team size was bigger, and we learned how to cooperate together in smaller groups, each group being responsible for a certain problem […] This, of course, required communication skills to understand the work of each group and combine everything together. We met once/twice per week and worked together. The discussions showed us that there were always other possible ways to think of a specific problem, and these discussions helped us identify the best possible way to solve a specific problem.

—Signal Processing Crew Darmstadt



[FIG2] The heart rate groundtruth of test set 2 and the estimates by the three winning teams. During the data recording, the subject performed various activities, including forearm and upper arm exercise, running, jumping, and push-ups. Thus, the subject's heart rate largely fluctuated. Most of the time, the estimates of the three teams closely followed the true heart rate changes.

SUPERVISORS' FEEDBACK

The most important ingredient in the recipe (to win the SP Cup) was the motivation of the students. We did our best to keep up a good team spirit in which their creativity could be channeled into new approaches. We had regular meetings, beginning with a kick-off meeting where the students got to know each other. We also provided the team with the communication infrastructure to ensure that the information flow between the students was efficient and transparent.

The SP Cup was extremely useful for students who could apply the concepts they had learned, e.g., in our lectures on adaptive filters and digital signal processing. Also, via the SP Cup, the students were able to implement and fully understand different adaptive filters, such as the least mean squares and Kalman filters. They understood, using real data, the tradeoffs between performance and computational costs.

—Dr.-Ing. M. Muma,
Signal Processing Crew Darmstadt

The students benefitted so much from the SP Cup that it cannot be fully explained in words. It gave them the opportunity to work on a real-world problem. It taught them how to study the literature and link fundamental and advanced digital signal processing algorithms to solve a complex problem. Moreover, it gave them hands-on experience to write technical reports. Although the SP Cup is primarily intended for undergraduate students, we had to explore many advanced algorithms to find an applicable solution. As a result, the insight that I have gained, on the related signal processing algorithms, are helpful to my teaching undergraduate, as well as graduate, courses. Specifically, it helps me to put forward appropriate examples and develop suitable assignments for my students. The benefit is not just limited to teaching courses but also extends to supervising research projects and theses.

—Prof. M.A. Haque, Supersignal,
who also led students
to win the first SP Cup

The SP Cup provides students with insight about how signal processing works in practice. Undergraduate students usually learn many signal processing theories and techniques, but only from textbooks and lectures. Through this competition, they collected a lot of information from various materials such as papers, videos, and discussions, and the combination of the collected information gave good results. It is important for students to learn how to approach problems. Several students even seriously studied sparse signal processing, Kalman filtering, and independent component analysis, which are beyond the scope of the undergraduate signal processing level, to try understanding the state of the art. Introducing the SP Cup in class interests students in signal processing. The explanation of the topic of the SP Cup, related to health monitoring, helps students find applications of signal processing in our daily lives. It is most useful to reduce the distance of the students to the signal processing area.

—Prof. S. Im, SSU

CONCLUSIONS

I am glad to see that many teams proposed effective algorithms to solve this challenge. Nevertheless, it should be noted that there is still much work to do so that the algorithms can work in various scenarios (e.g., different physical activities, different skin color, and different collection devices and PPG sensors). I hope that this edition of the SP Cup managed to raise students' interest in applying their signal processing skills to solve practical problems in wearable health care.

AUTHOR

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