

Platform for Teaching Sensor Fusion Using a Smartphone*

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A platform for sensor fusion consisting of a standard smartphone equipped with the specially developed Sensor Fusion app is presented. The platform enables real-time streaming of data over WiFi to a computer where signal processing algorithms, e.g., the Kalman filter, can be developed and executed in a Matlab framework. The platform is an excellent tool for educational purposes and enables learning activities where methods based on advanced theory can be implemented and evaluated at low cost. The article describes the app and a laboratory exercise developed around these new technological possibilities. The laboratory session is part of a course in sensor fusion, a signal processing continuation course focused on multiple sensor signal applications, where the goal is to give the students hands on experience of the subject. This is done by estimating the orientation of the smartphone, which can be easily visualized and also compared to the built-in filters in the smartphone. The filter can accept any combination of sensor data from accelerometers, gyroscopes, and magnetometers to exemplify their importance. This way different tunings and tricks of important methods are easily demonstrated and evaluated on-line. The presented framework facilitates this in a way previously impossible.

Keywords: electrical engineering education; student experiments; sensor fusion; inertial sensors; Kalman filter

1. Introduction

The usage of smartphones has seen an immense increase since the release of the first iPhone in June 2007. Today, most people carry around a smartphone that is a competent mobile computer designed for interaction with the environment. These smartphones are fitted with inertial sensors, GPS, light, and proximity sensors, as well as microphones, cameras, WiFi, and Bluetooth. The radio receivers measure signal strength from various wireless networks. The top-of-the-line models host even more and better sensors. This makes these devices highly interesting from a sensor fusion point of view, providing multi-modal sensory information and computing power in a small easily accessible package [1, 2].

From an engineering education viewpoint, this technological progress leads to the following two questions, which will be the focus of the paper:

1. How to design a technical solution that enables the use of the sensor capabilities of a modern smartphone in a user friendly and cost efficient way?
2. How to use the sensor capabilities in an educational framework such that it supports the students' learning of knowledge and skills in areas relevant for modern engineering education?

For both questions, there exist several alternative answers and approaches. One of the aims of the paper is to present a software platform that provides one possible solution to the first question. A second aim is to present an example of how the platform

can be used in an educational framework in terms of a laboratory exercise in a course in sensor fusion. The choice to use the platform in this way is motivated by constraints in terms of, e.g., time for the students and available time in the course. It is important to emphasize that several other learning activities using the platform are possible, e.g., problem or project based learning. However, it is outside the scope of the paper to give an exhaustive analysis of the use of the platform in different learning situations. Here, the main point will be to show that the platform enables learning activities that have not been possible before.

The use of smartphones as teaching devices has previously been investigated in the literature [3, 4]. These references discuss almost exclusively how to use smartphones as a portable delivery system for multimedia content and not how to utilize the sensory capacity of the devices. One exception is [5], where the authors use smartphones as a cheap and accessible alternative to traditional sensors. Another exception is our conference paper [6], which is an early report on the platform described here. Low-cost, portable and robust computing hardware for educational purposes has also been studied previously [7]. The authors especially emphasize the flexibility of the setup, where the equipment could be used for work in the classroom or as a take home lab. We think that this advantage is even more pronounced when using smartphones as the main sensor platform.

This article investigates the smartphone as a sensor platform for education purposes. Smartphones are indeed very accessible, powerful, user-friendly, and flexible given their price in comparison

to dedicated hardware for data collection. Further, since most students have a smartphone, their own personal gadgets can be used in the laboratory work. More specifically, the contributions of this paper are:

- A platform that consists of a smartphone and a computer together with adequate software. A user-friendly smartphone app, developed by the first author of this article, is used to log, visualize, and stream sensor data. The platform also includes cross-platform software allowing for full integration of streamed data in Matlab and Mathematica.
- A laboratory exercise that uses the platform as a tool to support the students' learning of filtering and sensor fusion. The laboratory exercise includes (in addition to the platform) a thought-through laboratory manual with suitably designed tasks and a Matlab code skeleton with the basic commands to access and visualize the sensor data. The laboratory exercise is part of a course in sensor fusion, [8], given by the Division of Automatic Control at Linköping University, and it treats design, implementation, and evaluation of *extended Kalman filters* (EKF) in different scenarios.
- An evaluation of the improved learning in terms of the new learning activities that are enabled by the platform and student feedback reports.

The remainder of this article is organized as follows. Section 2 gives a thorough description of the platform and presents the various functionalities that are available and how to use them. The educational benefits that emerge when having access to the platform are discussed further in Section 3. In Section 4, the laboratory exercise is described in more detail, both from a theoretical and student learning perspective. The evaluation and a final discussion are provided in Section 5 and Section 6, respectively. The paper ends with conclusions in Section 7.

2. Platform

The key component of the featured platform is the Sensor Fusion app for Android that has been developed at Linköping University. The app is available for free from Google Play Store¹ for anyone with a phone or tablet running Android Gingerbread (v. 2.3.3) or later. The app has more than 2,000 current installations, has been downloaded by almost 6,000 different users, and has an average rating of 4.27/5 in Google Play Store. This

¹ The Sensor Fusion app at Google Play Store: <http://goo.gl/0qNyU>

indicates that the app has reached out to a wide audience.

From the perspective of using the app in a laboratory exercise, the ability to stream and log measurements is important. From one unified view, it is possible to stream selected sensors to a server in real time and/or log the measurements to a file on the device for off-line analysis. The following sensor data is made available (if appropriate sensors are available) for streaming/logging in version 2.0b8 of the Sensor Fusion app:

- acceleration [m/s^2];
- angular rates from the gyroscope (raw and calibrated) [rad/s];
- magnetic field (raw and calibrated) [μT];
- pressure [hPa];
- proximity [cm] (some devices only provide a binary value near or far);
- light [lx];
- ambient temperature [$^{\circ}\text{C}$];
- position from the GPS (latitude, longitude, altitude) [$^{\circ}$, $^{\circ}$, m];
- orientation [unit quaternion] (this is a soft sensor);
- received signal strength (RSS) and other relevant information about WiFi networks in the environment; and
- RSS and other relevant information from cellular providers in the area.

The Sensor Fusion app is constantly evolving and more sensors are made available as new needs are identified.

When starting the app, the main menu appears as seen in Fig. 1. The menu offers the user the main functionality available:

- real-time visualization of sensor measurements using Select Sensor;
- logging or streaming measurements, using Log Data; and
- getting information about available sensors in the current device using Sensor List.

2.1 Logging measurements

The app can be used to log data for off-line analysis. The measurements are then stored locally on the phone in an expressive text format with one line per measurement. Each line contains a time stamp, a tag indicating which sensor produced the measurement, followed by the measured values. This format was chosen to be human-readable and easy to debug. A small Java library in combination with a short Matlab script can be used to read the log file and export it to a Matlab friendly format for further processing. The Java library also provides functionality to replay the log file and stream the measure-

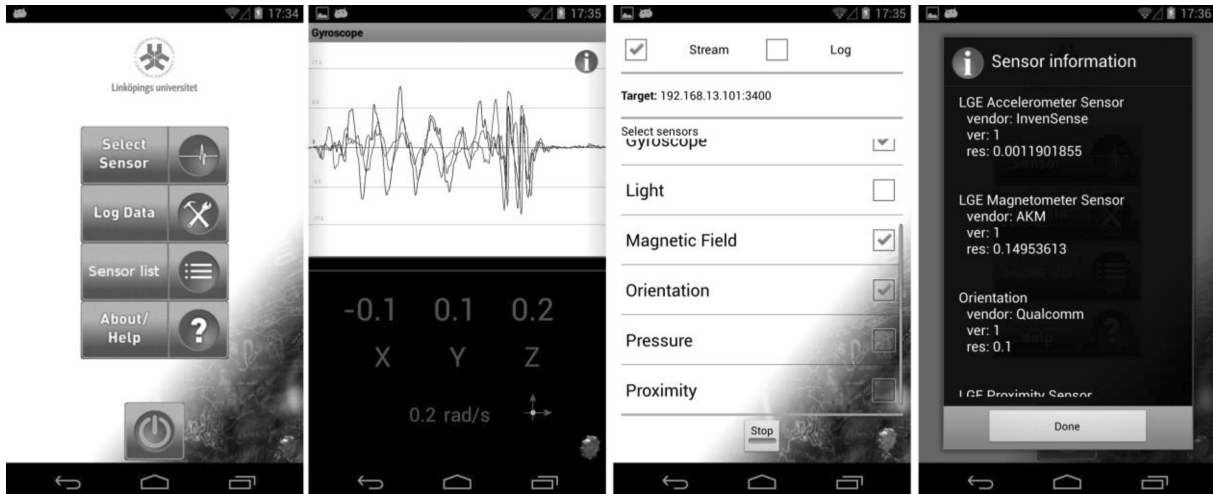


Fig. 1. Views from the sensor fusion app.

ments as the app would have done it. Both the Java library and the necessary Matlab code are available via a link [9] from the app's Google Play Store page.

The operation of the app can be configured to suite the intended usage by clicking on the red gear icon in the lower right corner of the screen. This brings up a configuration menu from which it is possible to change networking and logging settings, as well as the look of the app and the frequency of the measurements.

2.2 Streaming measurements

When streaming measurements, the app first opens up a TCP connection to a minimal server program running on the receiving end, e.g., Matlab on a laptop or a laboratory computer (See Fig. 2).

The app is fully configurable with regard to the IP address data is streamed to and which port is used. The app can hence make use of any available WiFi and mobile Internet connection to stream the data. This also means it will automatically make use of VPN connections if present. This allows for easy use in almost any environment. It also makes it possible to use either a laptop or the device itself as a wireless

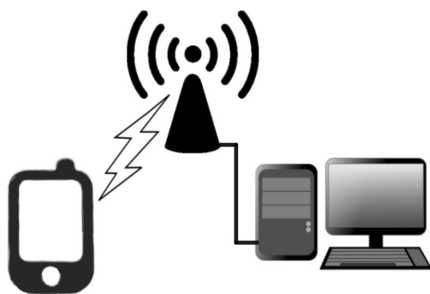


Fig. 2. System overview. The smart-phone, to the left, is connected via WiFi to a wireless access point, which in its turn is connected to the computer, shown to the right, via a wired network.

hotspot to connect the two to obtain a truly mobile system not relying on any external infrastructure.

The computer receiving the streamed measurements runs a small server program, e.g., the one provided in the free Java library described above. The Java library is written in such a way that it can be easily embedded in Matlab and Mathematica (this way allowing for full integration with these programs), or used stand-alone as a part of a Java program that utilizes the streamed measurements. The format used to stream the data is very similar to the way data is stored in the log file. Furthermore, it makes developing servers in different languages straightforward, if needed.

3. Educational benefits and context

The platform offers notable possibilities for various types of sensor fusion and signal processing experiments in engineering education. It enables learning activities that have been practically impossible until now. Gathering the type of data listed in Section 2.2 using separate sensors is a very difficult task, both from a practical and economical point of view. With the platform, the only components needed in order to start implementing sophisticated sensor fusion and signal processing algorithms are a standard smartphone and a computer. The app and the software to interact with it are available for free. To acquire separate sensors for the same task; to synchronize these sensors; and to finally integrate them in a measurement system is a considerable task. Hence, the platform has great potential as a tool in engineering education, and the platform offers several educational advantages:

- Access to a very cost efficient, powerful, and flexible system for data collection and signal processing.

- A simple and user-friendly interface to select sensors and which data to display.
- Implementation of the algorithms directly in Matlab, which is familiar to most students, lets the students focus on the algorithm implementation and tuning, instead of hardware and software details.
- A system that can be used almost anywhere as no special infrastructure is needed.

An important component of modern engineering education is to give the students not only the disciplinary knowledge, but also the skills to apply their knowledge to real world scenarios. In this process, there are several constraints with respect to both time and economical resources. The described platform enables a larger variety of learning activities within sensor fusion and signal processing, and it is primarily the availability of the students' time that limits which learning activities to arrange.

Here, the Sensor Fusion app and platform are presented in the context of a master's level course in Sensor fusion at Linköping University. The course is based on the textbook [10], and it comprises 6 ECTS credits. The learning activities encompass 20 hours of lectures, 16 hours of tutorial sessions, and two laboratory sessions. The examination comprises a four hour computer aided written examination and the two laboratory session. The Sensor Fusion app is used in one of the laboratory sessions. More information can be found via the course webpage [8].

The ambitions of the sensor fusion course are expressed in the course curriculum which states the following intended learning outcomes [8]:

[. . .] after the course the student should have the ability to:

- understand the fundamental principles in estimation and detection theory;
- implement algorithms for parameter estimation in linear and nonlinear models;
- implement algorithms for detection and estimation of the position of a target in a sensor network;
- apply the Kalman filter to linear state-space models with a multitude of sensors;
- apply nonlinear filters (extended Kalman filter (EKF), unscented Kalman filter (UKF), particle filter (PF)) to nonlinear or non-Gaussian state-space models;
- implement basic algorithms for simultaneous localization and mapping (SLAM);
- describe and model the most common sensors used in sensor fusion applications;
- implement the most common motion models in target tracking and navigation applications; and

- understand the interplay of the above in a few concrete real applications.

As will be illustrated below, the platform plays an important role for reaching the intended learning outcomes concerning implementation and evaluation of various types of sensor fusion algorithms.

4. Application example

The laboratory exercise is an important and vital part in all engineering education [11]. According to [12], the purpose is (i) to illustrate and concretize the teaching material, (ii) to make the students active, (iii) to teach the students practical skills, and (iv) to increase the students motivation to the work. One way to increase the motivation further is to use modern and high-technology tools [13], such as smartphones. This section outlines the usage of the Sensor Fusion app in the sensor fusion course, which we think fulfills these purposes.

4.1 The setup

The application example is a laboratory exercise where the task is to design, implement, and test sensor fusion algorithms to estimate the orientation of a mobile phone using measurements of its body acceleration, angular velocity, and the surrounding magnetic field. The orientation filter is a core component in any navigation system, and it integrates inertial information from gyroscopes and accelerometers, with magnetometer measurements and other supporting sensors that relate to the orientation of the platform with respect to the world. Orientations are furthermore very concrete and intuitive to understand, making it easy to illustrate properties of the estimate (See Fig. 3.). The sensors in a modern smartphone support estimating the phones orientation well, and built-in algorithms are provided to do this. These estimates

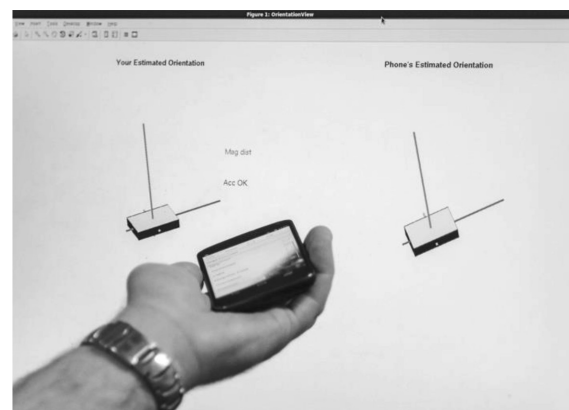


Fig. 3. Student evaluating his/her orientation estimate comparing the phone orientation with the estimated orientation on the screen of the own laptop.

can be used as a reasonable ground truth to compare and compete with.

The solution to the task of the laboratory exercise involves the following subtasks:

- Derive suitable (nonlinear) motion and measurement models for the various sensor combinations.
- Derive and implement an EKF.
- Tune the filter and evaluate its properties with respect to disturbances, etc.

The basic steps of estimating the orientation are the following. The smartphone's local coordinate system, S , relates to the global coordinate system, W , via the affine transformation

$$p^W = R^{W/S} p^S + t^{W/S}, \quad (1)$$

which describes the coordinate of a point, p , in the W frame as a function of the coordinate in the S frame, as illustrated in Fig. 4. The orientation of the smartphone is defined by the rotation $R^{W/S}$, whereas the displacement of the device is given by $t^{W/S}$. The displacement $t^{W/S}$ cannot reliably be estimated with inertial and magnetic measurements alone (without resorting to tricks and making additional assumptions); hence, the objective of the laboratory exercise is limited to estimating the sensor rotation $R^{W/S}$.

In the laboratory exercise, three kinds of measurements are used to solve the orientation estimation task. These are described in turn below. First, the *accelerometers* measure body accelerations, expressed in the sensor frame, S ,

$$y^a = (R^{S/W})^T g^0 + F + e^a, \quad (2)$$

where g^0 is the nominal gravity vector expressed in the W frame, F is the specific force acting on the device, and e^a is the measurement noise. Assuming negligible movements of the smartphone and only attempting to extract its orientation, the specific force, F is often ignored, i.e., $F \approx 0$. Measuring the gravity provides information to properly align the horizontal plane, but cannot help define a forward direction. The implications of this common approximation are illustrated in the laboratory exercise using simple experiments where the assertion is invalid.

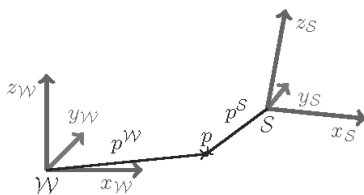


Fig. 4. Illustration of the two involved inertial frames; the world frame, W , and the sensor (smartphone) fixed frame, S .

The magnetic field has a component in the horizontal plane, and can hence define a forward direction. The *magnetometer* provides measurements of the magnetic field in the S frame,

$$y^m = (R^{S/W})^T m^0 + e^m, \quad (3)$$

where m^0 is the nominal magnetic field in the W frame, and e^m is measurement noise. The magnetic field is often heavily disturbed, especially in indoor environments, which raises important questions about the best way to use magnetic measurements and minimize the implications of disturbances. Again, the magnetic disturbances are illustrated using naturally occurring phenomena.

The last measurement used is the angular velocities measured with the *gyroscopes*. The angular velocities are measured in the S frame. The measurements can either be interpreted as normal measurements and treated analogously to the acceleration and magnetic field, or be considered measured inputs to be integrated to obtain an approximate orientation,

$$\begin{aligned} q_{k+1} &= e^{\frac{1}{2}S(\omega_k + w_k)T} q_k = \cos\left(\frac{T|\bar{\omega}_k|}{2}\right) q_k \\ &+ \frac{T}{2} \text{sinc}\left(\frac{T|\bar{\omega}_k|}{2}\right) S(\bar{\omega}_k) \\ &\approx \left(I + \frac{T}{2} S(\omega_k)\right) q_k + \frac{T}{2} \bar{S}(q_k) W_k. \end{aligned} \quad (4)$$

In this description, a unit quaternion, q_k , is used to efficiently represent the rotation $R^{S/W}$ at time k , and $\bar{\omega}_k = \omega_k + w_k$, where ω_k are the measured angular rates and w_k process noise (mainly consisting of measurement noise). Furthermore, S and \bar{S} are skew-symmetric matrix representations of the cross-product operation from left and right, respectively.

4.2 Theoretical aspects

The orientation estimation problem, as briefly described above, offers the possibility to deal with several important theoretical aspects of sensor fusion. When approaching the orientation estimation problem as a filtering problem, the students encounter both nonlinear dynamic and nonlinear measurement equations. Hence, they are forced to apply a nonlinear filter to solve the problem; in this case implementing an EKF. In the process, they must understand how accelerometers, magnetometers, and gyroscopes work in order to implement the appropriate dynamic equation as well as the measurement equations.

The problem also opens up for interesting discussions regarding how to represent rotations. Using a

rotation matrix would offer the most familiar representation for most students. However, the matrix representation is heavily over-parametrized, and a poor alternative for the task. Instead the laboratory instructions introduce quaternions for the filter constructed in the lab. This way the students get hands on experience of working with this important representation of objects in the SO^3 group.

Another important discussion is how the available measurements should be utilized. For instance, what is the difference between using the measurements of angular velocities from the gyroscope as inputs to the dynamic equation or as measurements, after augmenting the state with angular velocities, and how many biases need to be and can be estimated?

4.3 Practical aspects

The theoretical side of the laboratory exercise is naturally complemented by a wide range of practical experience as a consequence of working with data from commercial sensors in real time. In the exercise, the students are given a Matlab script to extract data from a smartphone in real-time. Based on this and the descriptions in the laboratory instructions, an orientation filter should then be constructed. In the process, the students are given ample opportunity to apply their filtering skills to a real application.

In order for the laboratory exercise to have the expected effect, it is important that the students spend their time doing sensor fusion rather than trying to understand a complex framework in which the task is performed. For this reason, it has been essential to design the platform in such a way that the students can work completely in Matlab, an environment they are familiar with from other courses. The students acquire practical skills by implementing the different steps in the orientation filter. The outputs from this filter can directly be compared to orientation estimates available in the phone.

To complete the task successfully, the students need to understand the available signals and the studied system. Therefore, the first thing the students are asked to do is to get acquainted to the sensors and how they behave. Here, the sensor views in the Sensor Fusion app are useful since they give instant feedback to external stimuli such as shaking or turning the phone (see Fig. 1). After that, the students are asked to design simple calibration experiments, analyze the results, identify biases, potential drifts, and other peculiarities of the sensors. Different devices suffer from different problems, which make the exercise extra interesting. Given their findings, the students should compensate their measurements. In practice this boils down

to compensating for gyroscope bias. The calibration experiment is also used to get a good initial tuning for the filter.

The need for outlier rejection is easily illustrated by asking the students to shake their smartphone and/or to introduce magnetic disturbances. Not only does the students' textbook estimate fail, it is also easy to observe that the orientation estimate provided by the internal software in the smartphone automatically compensates for these effects. The students then implement their own outlier rejection and can aim to outperform the built-in algorithm. Properly done, surprisingly good results can be achieved in short time. The experiences the students gain from dealing with practical signal processing, i.e., the difference between the theory and practice, are very important. Hopefully, the laboratory exercise makes the students much more aware of the differences between textbook examples taught in the lectures and practical problems.

4.4 Structure of the learning activities

During the first three years of using the platform in the course, a relatively straightforward learning format has been used in the laboratory exercise. The laboratory session is four hours, and the students work in groups of two. There are up to 16 groups of students carrying out the laboratory exercise at the same time, with access to two supervisors. A set of preparatory tasks must be completed beforehand. If not completed, the students are not allowed to participate in the laboratory session. Students who own a compatible Android device and who want to use their phone for the laboratory exercise may do so. This has turned out to be the majority of the students. Students without an Android device and those who do not want to use their own smartphone, are provided relatively cheap Google Nexus 5 smartphones to work with. To perform the laboratory exercise, the students connect the phones to the local wireless network to stream the data. The setup is illustrated in Fig. 2 and has not required any extra infrastructure to be installed in the laboratory workspace.

At the beginning of the laboratory exercise, a skeleton of Matlab code is provided, which the students extend during the lab. The code shows how to access the streamed data, and provides an easy way to visualize the estimated orientations (See Fig. 3). The code skeleton is available following the links on the app's Google Play Store page. The easy access to measurement data allows students with limited coding experience to focus on the sensor fusion aspects of the laboratory exercise, rather than on how to obtain data from the device.

5. Student learning, evaluation data, and student feedback

In this section, the impact of using the described sensor platform in engineering education is evaluated in terms of student learning outcomes and student evaluations.

5.1 Student learning

As mentioned, the examination in the sensor fusion course is carried out using a four hour written exam, with computer support, and two laboratory exercises. The laboratory exercise where the platform is used is examined by having the students demonstrate to the supervisor how the implemented algorithms work. This is just one example of a learning activity and examination where the platform can be used. More complex tasks requiring a team of students working over a longer time would be an interesting alternative. The other laboratory exercise is examined via a written report and a peer review process.

The platform enables learning activities that were previously impossible to carry out, and it is important to emphasize the knowledge and skills, which are developed and examined in the laboratory exercise based on the platform:

- Derivation of suitable (nonlinear) motion and measurement models for the various sensor combinations.
- Derivation and implementation of an extended Kalman filter for the various cases.
- Tuning and real time evaluation of filter properties with respect to disturbances, choice of design parameters, model errors, etc.

The first items could of course be examined with more traditional examination methods, but without the possibility to directly evaluate the results using real measurements. Using the platform, the students go through the entire engineering process from problem formulation, via algorithm design and implementation and tuning, to evaluation with different sensor configurations within the time frame of four hours. To the best of the authors' knowledge, nothing similar has been reported before.

5.2 Evaluation data

From a scientific viewpoint, it is of interest to provide quantitative data indicating that the use of the platform has positive effects on the students' learning. One possible data source could be the average grades on the regular written exam before and after the introduction of the platform. However, since the platform is used in a laboratory

exercise, with separate examination, and enables learning of knowledge and skills that were not possible to train and assess before, it is not obvious that the use of the platform will influence the grades of the regular examination. Hence, such data are considered to be less informative from this viewpoint.

A second possible data source is the web-based system for course evaluation that is used within Linköping University. Since the response rate in these evaluations is relatively low, such data have to be treated with care. Nevertheless, they still give useful information. In 2014 the students were asked to reflect on the usage of the smartphone in the laboratory sessions when they filled in the web-based course evaluation after the course. This was done by adding two specially designed questions to the general form. The statements used were:

- (i) "To work with real sensor measurements that I collected in real time during the laboratory session improved my understanding of the course material."
- (ii) "The goal with the laboratory session is to give better understanding for problems in sensor fusion and hands on experience from work with the Kalman filter. I think the goal was achieved."

The answers were given on a scale from 5 to 1 where 5 represents "Strongly agree" and 1 means "Strongly disagree". Based on 22 answers, the average grades were 4.32 and 4.27 for statements (i) and (ii), respectively. They furthermore gave the laboratory exercise the overall grade 4.18, which is above the grade for the entire course which was 3.59. Keeping in mind that this is a limited study, the platform and the laboratory exercise were appreciated by the students and supported them in their learning.

5.3 Qualitative student feedback

The following observations are based on interviews with students participating in the laboratory exercise using the Sensor Fusion app. During the laboratory sessions, some students indicated they had played around with the platform and the measurements before coming to the session. This is a good sign that the topic of the laboratory exercise and the easy access to the free supporting software has inspired these students to deepen their knowledge. Furthermore, the platform is compatible with a wide selection of smartphones making it very accessible. As a consequence, almost two thirds of the students used their own smartphone during the laboratory session.

Many students also found the laboratory exercise engaging and enjoyed using their own smartphone

as a sensor platform. They thought it was encouraging to see what they could do with the sensors many of them owned and carried around in their pocket each day. Hopefully, and as indicated by some of the students, they do not stop their laboratory work at the end of the laboratory session. Contrary, the easy access to sensor measurements invites to further experiments. At the same time, the data collected in real-time allows them to experiment and analyze different solutions as they go on.

Even though the laboratory exercise engaged most of the students, it also posed an initial barrier for a small number of students not acquainted to the technology. This is unfortunate, and shows the importance of clear instructions and not to rely on students being familiar with the technology.

6. Discussion

The new platform has improved the engineering education and the learning of the students by allowing for the introduction of new learning activities that were previously impossible to carry out, given time and cost constraints. Thanks to the platform the students are able to develop their skills concerning design, implementation, and test of sensor fusion algorithms in an entirely new way. The laboratory exercise using the platform assesses learning outcomes that have been relevant for a long time, but very difficult to examine without the platform as a tool. The key contribution is hence the role of the platform as an enabling factor for innovative engineering education in this field. These findings are corroborated by student feedback from course evaluation questionnaires.

Since the presented platform only requires a computer and a smartphone, this leads to new possibilities in mobile learning. The practical learning activities can take place anywhere and ultimately be included in distance education and massively open online courses (MOOC). A step in this direction has been taken in the course [14], which has used the described laboratory exercise and platform as the basis in a group project, which is not performed in a regular laboratory environment. We hope this article can help raise the awareness of the capabilities of the new smartphone technology as an educational tool.

7. Conclusions

The article has presented a platform for teaching sensor fusion. The platform consists of a normal Android smartphone running our specifically developed Sensor Fusion app. It enables real-time streaming of measurements to a computer where signal processing algorithms, e.g., the Kalman filter,

can be developed and executed in a Matlab framework. The platform enables students to solve a sophisticated sensor fusion task within a realistic time frame and with a very moderate cost. A wide range of applications are possible, and the article has focused on describing a laboratory exercise in a course in sensor fusion, in which the task is to estimate the orientation of a smartphone using measurements from its accelerometer, magnetometer, and gyroscope. The platform and the laboratory exercise have been very well received by the students, and the platform has received considerable attention also outside Linköping University. Thorough information about the course, the laboratory exercise, and the platform is available via the course web site [8]. The reader is encouraged to read and make use of the material as long as proper references are provided.

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