Evaluation of Fine-Granular GPS Tracking on Smartphones

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ABSTRACT

Smartphones with their GPS capabilities allow tracking in numerous scenarios at low costs. Whereas most scenarios need only coarse tracking, real-time tracking of competitors in sport events require fine-granular localization with high refresh frequencies. This work is conducted in the context of the sailing sports and tests the applicability of scenarios with fine-granularity requirements to today's available smartphones. We first describe our methodology to test smartphones for their suitability for fine-granular tracking. We execute a comparative study involving six modern smartphones running on three different mobile platforms and an additional dedicated GPS tracker. The GPS performance metrics accuracy, battery life, integrity and continuity were tested in four experimental setups, which were chosen with the intent to make the results applicable to real-world sports tracking scenarios. Our results show that with many of today's smartphones it is possible to fulfill fine-granularity requirements. But they also point out some devices' deficiency in integrity and continuity. Our results lead to guidelines relevant for GIS: tracking performance measurement, mobile platform and device selection, tracking application development and operation.

Categories and Subject Descriptors

C.3 [**Special-purpose and application-based systems**]: Real-time and embedded systems; C.4 [**Performance of systems**]: Design studies

General Terms

Experimentation, Measurement, Performance

Keywords

Mobile Localization and Tracking, GPS Performance, Evaluation, Smartphone Application for GIS

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1. INTRODUCTION

With the emerging proliferation of smartphones, localization techniques like the global positioning system (GPS) have become ubiquitously available to consumers. Combined with mobile Internet, services like Google Latitude and Foursquare that augment information systems with location-based information have been created. These so-called location-based services (LBS) are considered to hold the highest commercial potential among all mobile applications[1]. While for LBS it is in many cases sufficient to derive approximate locations without having to frequently refresh the location, the situation is different in scenarios with fine-granularity requirements like tracking in sailing sports.

If we consider applications that make use of localization functions on smartphones, we can observe different granularity requirements. An example is Foursquare, where people can communicate their current location and their location history to friends. For privacy reasons [2], in some cases it is even necessary to have a coarse localization granularity, i.e. a precision up to the city-level is sufficient. Other applications are car navigation systems [21], where high accuracy and frequent location updates are needed to ensure reliable routing. The third application that we consider to be the main use case of our work is the tracking of real-time events like sport competitions. Given that all competitors are equipped with GPS trackers, the location should be updated at high accuracy. Furthermore, another granularity-dimension arises: in order to be able to visualize the state of the competition at nearly real-time, the location has to be transmitted with frequent updates over a wireless network to a back-end.

Our work has the third, real-time tracking scenario as main use case. We note that there are two dimensions of granularity that have to be considered: *fine-grained GPS updates* and *fine-grained transmissions* through a wireless network. Along with these two points, it is crucial to measure the GPS performance parameters *accuracy*, *availability*, *integrity*, *continuity* [12].

Motivated by this scenario, our work adds to the knowledge body of fine-granular location tracking. We aim at answering the following questions: Are smartphones suitable for fine granular location tracking? If yes, how can this be tested? How do smartphones perform compared to dedicated trackers? To approach these questions we provide an evaluation of the granularity and performance requirements

[1]"Gartner Identifies 10 Consumer Mobile Applications to Watch in 2012". `http://www.gartner.com/it/page.jsp?id=1544815`

on six modern smartphones with GPS sensors, running on three different mobile platforms (Apple iOS, Google Android and Microsoft Windows Phone 7 (WP7)). Furthermore, we include a dedicated GPS device with GSM capability that is used in commercial tracking solutions in the evaluation in order to have a comparative reference for the smartphone results. The study evaluation is done with four experiments. They intend to assess 1) the accuracy of the trackers at a given reference point, 2) their battery life depending on the GPS sampling frequency and 3) the GSM transmission update frequency and 4) the combined performance metrics during a boat cruise.

Overall, this paper provides results valuable for both research and practice, and contributes to research towards mobile applications for GIS with smartphones. Using our evaluation methodology, it is possible to evaluate future smartphones for their suitability for fine-granular location tracking. It gives guidelines to developers to master challenges that arise for a practical deployment of smartphones for GPS tracking. For practice, it advises providers of low-cost tracking solutions, especially for sports events, with results regarding the suitability of smartphones.

Real-world use case: tracking sailing regattas

This research is part of a research project that aims at developing and evaluating low-cost tracking solutions for the sailing sports. Using smartphones as tracking devices is an obvious choice because these devices have the needed GPS sensors integrated and allow real-time transmissions to a backend via GSM cellular network.

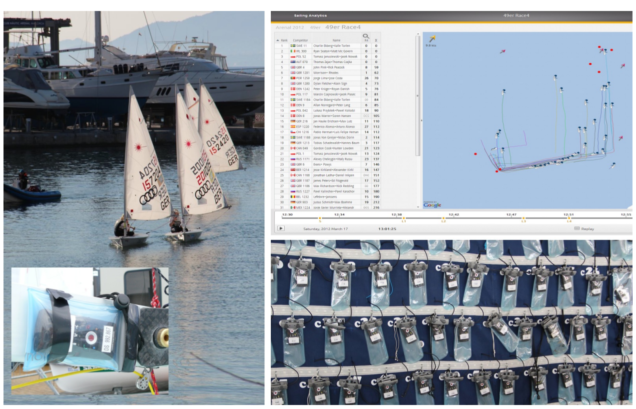

Figure 1. GPS tracking in the sailing use case: GPS trackers (bottom right) are attached to sailing boats (left) during a race. A visualization component shows live race analyses (top right)

Smartphones further have the advantage that sailors can use their private devices with the appropriate tracking application installed in their training sessions without the need for additional infrastructure. Furthermore, race analysis applications could run directly on the smartphone and provide the sailors with valuable feedback after a sailing training. The overall scope of the project is to use low-cost GPS trackers for real-time tracking and to provide live-visualization and analytics solutions to athletes, spectators, trainers and race administrators. An impression of this setting is given in Fig. 1, where GPS trackers continuously send data to a backend during a race, where the data is subsequently processed and visualized.

The paper is structured as follows: Section 2 gives an overview of relevant related work, section 3 presents the GPS tracking methodology and the experimental design of our study. In section 4 we present the results from our experiments, which opens space for discussion and and the elaboration of guidelines in section 5.

2. RELATED WORK

For real-time tracking scenarios we consider GPS to be the most suitable candidate because of its precision and the worldwide availability without additional infrastructure needs. GPS is a military system and allows in its public version only limited accuracy [8] of up to five meters. Besides GPS, there are several other localization systems available. Since GPS is limited to outdoor applications, indoor positioning systems have been proposed in [6] and [13]. Other systems use triangulation over GSM [22], WiFi [16] or Bluetooth [1] instead of GPS sattelites. The time until a first fix of GPS (approximately 45 sec) has been improved with such techniques, which lead to so-called assisted GPS (A-GPS) [5]. *Differential GPS* improves accuracy with additional long wave beacons whose location is precisely known, allowing for theoretical precision of up to 10 cm [18]. Since receivers for those signals are not implemented in most consumer grade trackers, we are in our work restricted to common GPS. GPS tracking on smartphones has recently gotten much attention in the research community. Other popular services are LBS, which have been extensively researched (e.g., [19][24]). GPS sensing is resource intensive [9] and so numerous papers investigate the tradeoff between GPS performance and battery constraints. The observation that GPS is usually less accurate in urban areas is used by [17] to lower the sensing rate in these situations. Other researchers ([14][10]) propose to use other sensors like the accelerometer to detect movements and to adapt the GPS sensing frequency accordingly. Real-time tracking applications comparable to our tracking scenario have, for example, been investigated in work on vehicle tracking [11] or semantic trajectory determination [25].

Other related work concerns tracking techniques for real-time sports events. Here especially optical, camera-assisted approaches (e.g. [3][7]) are an alternative tracking method that however require large infrastructures and thus limit the ubiquitous and low-cost applicability compared to our GPS approach.

3. STUDY DESIGN

To approach the question of whether smartphones are suitable for fine-granular GPS tracking, we designed a comparative study that aims at assessing *accuracy*, *availability*, *integrity* and *continuity* of different GPS trackers. Those four dependent variables are considered as the key dependent variables for assessing positioning services (e.g., according to [4][12]) like GPS or Galileo [15]. *Accuracy* describes how precisely a measured coordinate matches a well known reference point. *Availability* has two aspects: First, it describes the availability of GPS signals in our field of operation and second, it describes the battery life of the trackers during the tracking scenario. *Continuity* describes the requirement that it should be possible to frequently get GPS fixes. *Integrity* denotes the property that the derived location actually falls within the tolerated accuracy-margin.

Table 1. Platforms, OS, trackers, chipsets and applications used for the study

Tracker	Platform/ OS	GPS Chipset	Application
Samsung Galaxy SII	Android 2.3.3	Qualcomm SiRFstarIV GSD4t	self-developed
Samsung Nexus S	Android 2.3.6	Broadcom BCM4751GPS	self-developed
Apple iPhone 3GS	iOS 4.2.1	Broadcom BCM4750GPS	self-developed
Apple iPhone 4	iOS 4.3.5	Infineon PMB2525	self-developed
Nokia Lumia 800	Windows Phone 7	Qualcomm MSM8255	self-developed
Samsung Omnia 7	Windows Phone 7	Qualcomm QSD8250	self-developed
BeniFone	proprietary	SIRF Star III 20	proprietary

Our study investigates all those variables by taking as independent variables six different smartphones running on three mobile operating systems, and an additional commercial GPS device intended for tracking sport competitions. All devices have different GPS chipsets. For the smartphones we developed own tracking applications using the platforms' API, while the professional grade tracker had a proprietary software pre-installed. The independent variables are summarized in Table 1.

For fine-granular GPS tracking, there are several influence factors that have to be investigated. In our study we consider the following points: 1) the mobile device, 2) the GPS chipset hardware built in the mobile device, 3) the battery capacity of the mobile devices, 4) the platform OS with its API and the connected programmatic aspects and 5) the testing environment we chose for the study.

Mobile Devices.

Figure 2. Devices and platforms used for the study

The choice of the mobile devices used in the study (see Fig. 2) depend on the following factors: in order to provide GPS tracking applications with equivalent configurations, we selected phones running on platforms where developers can implement their own applications. The three most popular platforms that provide development environments are Google Android, Apple iOS and Microsoft Windows Phone (WP). On these platforms, we choose the two best-selling smartphones in our country by the date of our study. To have a comparison with dedicated, commercial GPS trackers, we used the BeniFone tracker with its proprietary software as a reference. The devices themself, for example with their case material, could potentially influence the GPS tracking performance.

GPS Chipsets.

Responsible for GPS on hardware level is the chipset integrated to the mobile device. They could be either a standalone component, but are today usually integrated on a System-on-a-Chip (SoC). The investigated mobile devices all use slightly different GPS chipsets from the manufacturers Broadcom, Qualcomm and Infineon.

Battery capacity.

The battery life of the mobile device not only depends on the GPS and GSM activity. Different devices are equipped with different battery capacities. In our evaluation, all devices were equipped with Li-Ion (3.7V) cells of capacities ranging from 900 mAh (BeniFone) to 1650 mAh (Galaxy SII). The other devices had a capacity of 1219 mAh (iPhone 3GS), 1420 mAh (iPhone 4), 1500 mAh (Nexus S and Omnia 7) and 1450 mAh (Lumia 800). Since the actual capacity of Li-Ion cells decreases with increasing loading cycles [23], we used almost new cells with a comparable total cycle number in order to exclude aging effects from the evaluation. For the results it is on one hand interesting to see absolute battery times to observe the mobile devices' performance. On the other hand, one could abstract from absolute capacities to get normalized results.

Programmatic Aspects.

Apart from BeniFone's dedicated GPS device with preinstalled proprietary tracking software, we developed the tracking software for the iOS, Android and Windows Phone platforms. Those platforms provide developers with software developer kits and provide APIs to access GPS functionality. Where possible, we explicitly turned off A-GPS functionality that could affect result integrity. Details on the implementations are given in section 5.2.3.

Another programmatic aspect is the implementation of the coordinate transmission to the backend server. For this purpose, we developed a server component that exposes a RESTful interface to the Internet, which allows mobile clients to submit GPS coordinates. To reduce communication overhead to a minimum, we chose the compact JSON data format. The mobile clients then transmit the GPS coordinates through a simple HTTP POST request to the server. We note that the REST/JSON combination [20] is a popular choice for mobile applications today.

Testing Environment.

The environment for the evaluation of the GPS trackers was chosen to fulfill two properties: First, it has to be ensured that the GPS performance properties could be determined in a controlled environment, and so we choose a local reference point in Zurich, Switzerland for accuracy measurements. The measurement of the battery life was done at the same location. Second, we especially consider the field of application of fine-granular GPS tracking: the sailing sports. For simulating this setting, we did the evaluations during a boat cruise on Lake Lucerne in Switzerland.

Experiment 1: Accuracy at a given reference point

Cartography institutes of local governments provide several reference points in the country, with precisely known coordinates. They are used to develop topological surveys of the surroundings. For example, the Swiss Federal Office of Topography *Swisstopo* publishes reference points online[2].

Figure 3. Experiment 1 setup: Tracking at reference point.

For the first experimental setup of our study, we selected a nearby reference point, placed the seven tracking devices on it and refreshed the GPS coordinates every second. The experiment ran one hour and preceded a "warmup" phase where all devices could get GPS fixes and were calibrated with updated adjacency lists. The tracking setup is illustrated in Fig. 3. The accuracy of the GPS trackers can be examined by measuring the difference between the sensed data and the reference point's actual coordinate. Furthermore, integrity can be evaluated by frequently updating the coordinates and observing deviations.

Experiment 2: Availability - Battery life (GPS)

In experiment two, the influence of GPS sensing on battery life was tested by refreshing the GPS signal each second. To achieve a controlled environment and exclude external effects, the coordinates were not transmitted via the GSM network, the screen was kept "OFF" and no other applications except OS services were running concurrently on the smartphones.

Both experiment two and three were done by placing the tracking devices in weather proof plastic boxes on the roof of our institution's building. Measurements were started simultaneously and lasted until the devices stopped sending or sensing because of the empty battery. We note that for the GSM test, all devices connected to the same cellular service provider's network and had very good 3G reception.

Experiment 3: Availability - Battery life (GSM)

The third experiment intends at evaluating the impact of GSM transmissions to the battery life. Frequent transmissions of location data is necessary in the sailing scenario where a backend server should be able to show and process live data of a race. To exclude the energy consumption of the GPS sensor, we sent dummy coordinates over the 3G cellular network with sending cycles of one second. To demonstrate how the battery life can be further extended, we did an additional measurement using an external battery pack attached to the Galaxy SII device.

[2]`http://www.swisstopo.admin.ch`

Experiment 4: Availability, accuracy, integrity and continuity in a moving scenario

Experiment four is intended to simulate GPS tracking during sailing competitions. For this purpose, the trackers were brought to a five and a half hour boat cruise on Lake Lucerne. Contrasted to the previous experiment that run in a more isolated and controlled environment, this setting is more similar to a real-world setting. Here factors such as GSM reception and GPS connectivity dynamically change over time because of the moving scenario. The setting is illustrated in Fig. 4.

Figure 4. Experiment 4 setup: evaluation during boat cruise

This experiment intends at giving results on several performance variables of GPS. The first one is accuracy: compared to experiment one, absolute statements can't be given because of the missing reference points during the boat cruise. However, deviations between the tracking devices can be measured, as well as rough observations can be made (i.e. we approximately know the locations from the scheduled route of the boat cruise). For availability, realistic measurements are done by measuring the battery level after the boat cruise while refreshing the GPS sensors and transmitting data via GSM every second. An important measurement regarding GPS fix availability also determines continuity: Here we measure the intervals between two sensed GPS coordinates: Because we requested for GPS updates with a refresh frequency of 1 Hz, our measurement has a granularity of one second (requests done in times $t_1, t_2, ...$). If not each second an update is available, we can observe an interruption in GPS continuity (e.g. if updates are received in t_1 and t_4, the interval between receiving coordinates is $3s$).

4. EXPERIMENTAL RESULTS

A summary of the experimental settings as described in the previous is given in Table 2. This section describes and discusses the experimental results, grouped by the GPS performance variables: accuracy, availability, integrity and continuity.

4.1 Accuracy

Measuring the accuracy of the sensed GPS coordinates was done during the first experiment. All tracking devices were placed on a reference point with a well known coordinate. The results are visualized in Fig. 5.

We observe that all trackers manage to achieve accuracies with deviations from the reference point of at most five meters. This is a decent result for public GPS without the usage

Table 2. Experiment settings

	Scenario	GPS	GSM	Measurement
1	reference point	1 Hz	-	accuracy
2	outdoor fixed	1 Hz	-	availability (battery life)
3a	outdoor fixed	-	1 Hz	availability (battery life)
4	boat cruise	1 Hz	1 Hz	accuracy, availability (battery life), integrity, continuity

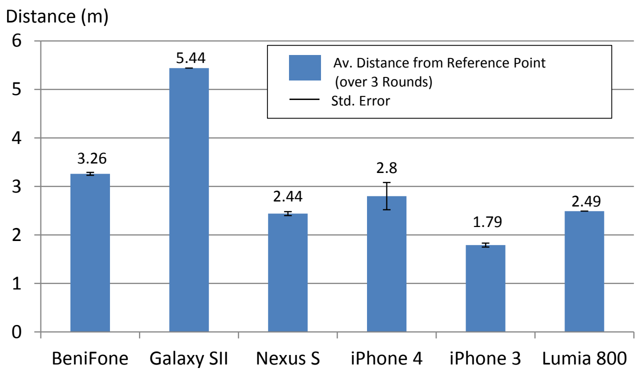

Figure 5. Experiment 1: Accuracy and standard error of GPS sensing at reference point.

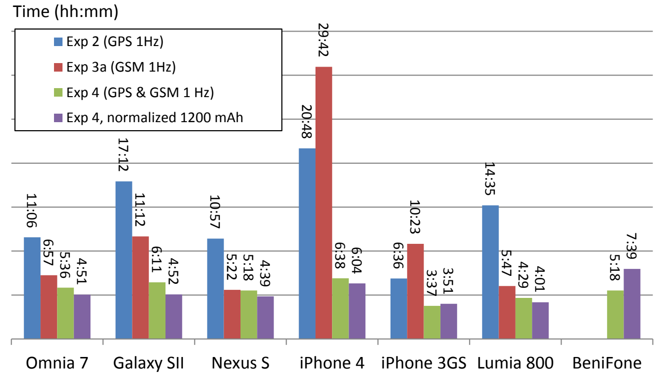

Figure 6. Battery life in experiment 2, 3 and 4.

of differential GPS. The results range from the iPhone 3GS with 1.79m deviation to the Galaxy SII device with 5.44m deviation. All smartphones in the test except the Galaxy SII managed to achieve slightly better accuracy than the BeniFone GPS tracker. It is also noteworthy that the trackers usually showed no variation in location during the GPS refresh. The iPhone 4 showed the highest variation of about 0.5m, which should however in practice be negligible. We omit to display the Omnia 7 results in the table. This device achieves an accurate minimal deviation of 2.2m, but frequently switches between GPS and A-GPS, leading to deviations of several hundred meters.

4.2 Availability

In experiment two and three, the battery life of the trackers was measured while refreshing GPS coordinates every second without transmitting them via GSM (experiment 2) and by transmitting dummy coordinates every second via GSM (experiment 3). During the boat cruise in experiment 4, both GPS and GSM where active. The results are displayed in Fig. 6.

The first observation is concerning the difference in battery life between experiments 2 and 3. Interestingly, on devices running on Android and Windows Phone, transmissions via GSM seem to dominate energy consumption compared with GPS sensing. On both Android devices, experiment 2 leads to approximately double battery life than experiment 3. We observe that the battery drain dominated by GSM transmissions can be reduced by transmitting only every five seconds on the Android devices. In this case battery life is tripled compared to the sending every second. On the Windows devices the same effect is visible, but less distinctive. On iPhone devices however, the situation is reversed and GPS sensing uses more battery than GSM, which could be either influenced by the iOS operating system or by the iPhone hardware. For practice it might also be interesting to attach an extra battery pack to the devices. Attached to the Galaxy SII device where the effective capacity was tripled, we consequently observed a tripled battery life. Experiment 3a was repeated with reduced transmission frequency of 1/5 Hz on the Galaxy SII and Nexus S (battery life tripled) and the Lumia 800 (battery life 30% increased).

The results from experiment 4 show that there are several smartphones that achieve a longer battery life than the dedicated BeniFone GPS device. Namely, the Galaxy SII, Nexus S, iPhone 4 and Omnia 7 run for over five hours. It should for this reason be suitable for tracking sports competitions like sailing regattas, given that the tracking is only enabled during races.

In addition to battery life, availability of GPS fixes can be derived from the GPS sending intervals in Table 3. Here all devices except the iPhones, the Omnia 7 and BeniFone have a one-second interval in over 98% of the cases.

4.3 Integrity

By integrity we understand that the measurements by the devices actually fall within a well-tolerated margin that is typical for GPS, i.e. five meters. The accuracy measurements from experiment 1 (Table 2) show that all devices manage to achieve this integrity in a stationary case.

During the boat cruise experiment 4, it is difficult to make statements on integrity because of the missing reference point. In the case of the Omnia 7, we observed that the location frequently switched between an accurate one and one that was far off track. We assume this is caused by both hardware and software: the GPS hardware is not able to continuously get GPS updates and the software switches to inaccurate A-GPS in these cases. Windows Phone 7 doesn't allow to prevent A-GPS to be used in the API. The other WP7 devices seems to have a more stable GPS chip and didn't show this pattern. Another integrity affecting behavior was shown by both iPhones: they have shown accurate results but delivered the coordinates with a delay of approximately 15 sec. In the moving boat cruise scenario, the coordinates at a given time were so up to 180m off target, as shown in Fig. 7. This is especially harmful for our real-time scenario. Techniques like trajectory smoothing [25] could however be employed to discard such high deviations.

4.4 Continuity

For fine-granular, dynamic applications, continuity is of especial importance. It shows that the trackers have a stable fix with the GPS satellite and receive frequent updates. That there are significant differences in continuity between the devices becomes apparent in Fig. 7, where there is a deviation of $180m$ between the trackers at a given time. This is on one hand to be explained with difficulties of some devices to continuously get GPS updates. On the other hand this is caused by the iPhones' integrity anomaly as described in previous section.

Figure 7. Continuity/Integrity: Deviation up to 180m at a given time, visualized with Google Earth

Table 3 presents the continuity results in more detail. We observe that the two Android devices as well as the Lumia 800 are capable to get updates every second in over 98% of the cases. Omnia 7 still achieves this in 93%, while both iPhones only achieve this in about 40%. This leads to the presumption that the iOS API doesn't allow for delivering highly continuous GPS data. Further we note that the BeniFone sensor's firmware only implements refresh rates up to $2s$, which is the reason for the 0% result. All devices manage to achieve intervals of at most $3s$ in over 90%, while BeniFone performs worst here.

Table 3. Experiment 4: GPS sending interval

Device	GPS pts received	Interval $\leq 3s$	Interval $= 1s$	Max. interval
BeniFone	6346	91.27%	0.00%	$7s$
Galaxy SII	22307	99.99%	99.98%	$4s$
Nexus S	15986	99.32%	98.41%	$968s$
iPhone 4	12440	97.25%	43.64%	$94s$
iPhone 3	5773	94.61%	41.52%	$410s$
Lumia 800	16087	99.98%	99.75%	$12s$
Omnia 7	16737	98.49%	93.17%	$22s$ (AGPS)

Another important metric is the maximal measured interval. Here, Galaxy SII ($4s$) and BeniFone ($7s$) are the most reliable, followed by the Windows devices. The iPhones and the Nexus S however show inferior results here with maximum intervals of several minutes. In the Nexus S case, it is assumable that there is a hardware problem since the other Android device shows an excellent result.

5. DISCUSSION

The results show that all tested devices achieve high accuracies within the GPS five meter margin. Also the battery life of most tested devices is competitive with the dedicated tracker. Although accurate at a given fix point, the integrity results show significant differences among devices: delayed GPS coordinates in the iPhone case and unpredictable switching between GPS and A-GPS in the Omnia 7 prohibit an application in real-time scenarios. In the continuity evaluation, some devices have sporadically shown very high intervals where no GPS coordinate updates were received. Since there were other trackers like the BeniFone device or the Galaxy SII that didn't show these intervals, we can exclude that the GPS satellites were technically not reachable, for example because of atmospheric anomalies. The effect of these long update intervals are very illustratively displayed in Fig. 7 that shows a deviation of $180m$ between trackers at the same time, a no-go for sailing tracking. There were two devices in our test that didn't show severe deficiencies in integrity and continuity, namely the Galaxy SII and the Lumia 800.

5.1 Limitations

There are a couple of limitations in our study that are worthwhile being discussed. One point is the limited number of six smartphones that we used for our evaluations. We selected two devices each running on the same platform, and chose the best sold devices for those platforms by the time of our study. For reliably determining what factor (e.g. operating system, GPS chipset, other hardware) actually influenced some of the deviations in results would however require more device combinations to be evaluated, or the same devices running with different operating system versions. Since the production cycles of smartphones are quite short, the evaluation should be repeated with new device generations. Another limitation arises from the location we choose to experiments one and four. To have even more significant results regarding accuracy or continuity, one should run the evaluations on several reference points and on several boat cruises on different locations in order to exclude potential external factors that were not controlled. Another point arises from the API and the program code we used for the evaluations: in the iOS code we were not able to achieve fine-granular results where GPS is refreshed every second. As this depends on the platform API, it is possible that changes in future versions of the platform improve the results.

5.2 Guidelines

Motivated by the results of our evaluation and our experiences during development and planning the study setup, we believe it is worthwhile to give some recommendations and guidelines to developers and researchers who want to follow our approach of fine-granular GPS tracking on smartphones. Especially because production cycles for smartphones are very short, it is important to give some guidance for future evaluations on new devices or new platform versions.

5.2.1 Measurement tracking performance

It is important to measure all GPS performance metrics. Our results show that all evaluated devices achieve high accuracy at a given reference point with a precision of at most five meters. Using only this result is however not sufficient. In the continuity measurement it was apparent that some of the devices were not suited for frequent GPS updates, which is crucial for dynamic, real-time scenarios such as sport competition tracking.

5.2.2 *Selecting platform and device*

In our use case of sailing tracking, the tracking solution should be made accessible also for the sailors' private smartphones. This leads to the recommendation that the most popular devices should be given priority in the selection of appropriate tracking devices.

One could assume that a platform-independent HTML5 solution that runs on all smartphones would be the ideal choice. There is however no direct control over the GPS refresh rates. The deciding factor is here the browser HTML5 implementations, which would have to be evaluated on all mobile platforms in future work. A general statement on HTML5 suitability is so not possible.

In near future, smartphones are likely to be able to combine GPS with the Russian GLONASS sattelites[3]. Also the European Galileo system might be supported, which will increase localization accuracy in the future.

5.2.3 *Developing a tracking application*

It is crucial that the tracking software is carefully developed. An example pitfall lies in the API like in the iOS case, which doesn't allow to gather frequent GPS updates. The API has there to be tricked by explicitly shutting down the platform's GPS service every second and restarting it again. Just requesting secondly updates doesn't lead to the desired result.

In all the different mobile platforms the typical way to get GPS locations from the operating system is similar. After instantiating a manager object from the location API, one passes the desired location parameters to this object, together with a callback function that handles location update events. Of especial interest is how location updates and explicit GPS usage as location provider can be configured. In the Android case (Listing 1), both refresh rates and updates depending on distance can be specified. GPS can explicitly selected as location provider.

Listing 1. Android code snippet

```
//instantiate location manager object
LocationManager locationManager = (LocationManager)
        getSystemService(Context.LOCATION_SERVICE);
//pass settings and start data acquisition at once
//requested time between two fixes in ms and distance in m
locationManager.requestLocationUpdates(
        LocationManager.GPS_PROVIDER, 1000,
                0.0, sailingLocationListener);

@Override
public void onLocationChanged(Location location) {
// handling changed location }
```

In the WP7 and iOS case (Listing 2 and 3) it is only possible to specify a movement threshold on which the location should be refreshed. To explicitly get refreshes every second, the API has to be tweaked by restarting the location services every second. Otherwise, one can't guarantee high-frequent updates. Manually requesting updates every second might not be sufficient since the OS could deliver cached locations if the movement threshold was not exceeded.

Listing 2. Windows Phone 7 code snippet

```
//instantiate location manager object
//accuracy's type is GeoPositionAccuracy
GeoCoordinateWatcher watcher = new
        GeoCoordinateWatcher(accuracy);
//pass settings
watcher.MovementThreshold = 0.0;

watcher.StatusChanged +=
        new EventHandler<GeoPositionStatusChangedEventArgs>
                (watcher_StatusChanged);
watcher.PositionChanged +=
        new EventHandler<GeoPositionChangedEventArgs
                <GeoCoordinate>>(watcher_PositionChanged);
watcher.Start(); //start data acquisition

void watcher_PositionChanged(object sender
         GeoPositionChangedEventArgs<GeoCoordinate> e)
{ // location handling }
```

Another difference is that WP7 and iOS don't allow for explicitly specifying GPS as location provider, but only an accuracy. A-GPS will be used until a GPS fix is there. In practice, one should in these cases await a warm-up phase after which GPS is selected as location provider with highest accuracy.

Listing 3. iOS code snippet

```
//instantiate location manager object
CLLocationManager locationManager =
        [[[CLLocationManager alloc] init]];
//pass settings
locationManager.delegate = self;
locationManager.distanceFilter = 0.0;
locationManager.desiredAccuracy = kCLLocationAccuracyBest;
//start data acquisition
[locationManager startUpdatingLocation];
- (void)locationManager:(CLLocationManager *)manager
        didUpdateToLocation:(CLLocation *)newLocation
                fromLocation:(CLLocation *)oldLocation {
//location handling }
```

In the dedicated BeniFone trackers, the devices can be remotely configured via SMS to change the sending frequency. As this increases battery life and therefore availability, smartphone solutions should implement similar functionality. There are even possibilities to adaptively change sensing frequencies depending on the device's current context (see e.g. [10]).

5.2.4 *Operating the tracking application*

If dedicated GPS trackers like the BeniFone device should be replaced by smartphones, one has to consider the increased complexity of the smartphone that could lead to increased user operating errors. To avoid them, one should in the best case lock the device during a tracking event to ensure that users don't accidentally disable or reconfigure the software. Also other applications running on the smartphone that are not required for tracking should be disabled.

6. CONCLUSION

This paper shed light on the question whether smartphones are suitable to be used for fine-granular GPS tracking for scenarios such as sailing competitions. Our evaluation shows that this heavily depends on the chosen smartphone. There are indeed devices that show superior GPS performance than dedicated GPS trackers. After the evaluation of the GPS performance metrics accuracy, availability, integrity and continuity, we can conclude that there are smartphones that are well suited for scenarios with fine-granularity requirements such as tracking for the sailing sports. Following our study results, the decision was taken to use Samsung Galaxy SII devices for sailing tracking because of its good performance in all GPS metrics. However, a conclusion with equal importance is that not all tested

[3] http://www.reuters.com/article/2010/10/27/telecoms-russia-duties-idUSLDE69Q1KX20101027

devices fulfill the requirements. We therefore recommend to follow our guidelines derived from the study to ensure seamless integration of smartphones for tracking scenarios. Using smartphones opens new areas of application for GPS tracking and makes it accessible for private users without the need for complex infrastructure in place. Applying them in the sailing scenario will in the future deliver more relevant field data.

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