Noisemap - Multi-tier incentive mechanisms for participative urban sensing

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ABSTRACT

Noise pollution is a problem increasingly acknowledged by authorities and governments around the globe. At last year's PhoneSense we presented Noisemap, a participating sensing application to accurately measure noise pollution. Noisemap incorporated frequency calibration to overcome the limited microphone hardware. The challenge remaining is how to motivate smartphone users to sacrifice their time and battery on measuring noise.

In this paper we present a completely new version of Noisemap. We implemented four different incentive schemes categorized as *Internal Incentives* and *External Incentives*. These schemes drive user engagement and data quality.

A user study was conducted with 49 users divided into three groups. As expected the average measurements taken per user increased from 402 to 3,357 as the number of incentive schemes increased. Over the course of 7 weeks the users captured more than 85,000 measurements, measuring for more than six hours on average.

1. INTRODUCTION

Noise pollution is ever increasing in urban environments causing major health problems [9, 4]. As an example the European Union acknowledges the potential damage of noise in their Environmental Noise Directive [3]. This directive regulates that all member states need to gather data about noise pollution in order to propose efficient noise control measures. Data is gathered in two separate runs from sources such as traffic, industry, airports and railways. Unfortunately, capturing data is very expensive both in hardware as well as manpower. Only a few real measurements are taken. Most of the data is generated, and most of the noise pollution map is then colored, using simulation (cmp. Fig. 1[1]).

[1]Picture Source: `http://www.hlug.de/?id=525`

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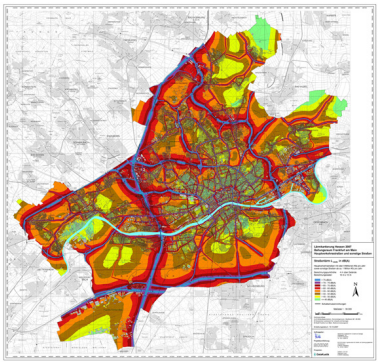


Figure 1: Noise pollution map of Frankfurt, Germany

Today each mobile phone is equipped with a microphone and GPS. They are the perfect platform for mobile noise measurements. Furthermore, their ubiquity and mobility can complement the coverage of traditional sensor networks. Two main challenges, data quality and data quantity, must be addressed in any application. The data quality in participatory sensing suffers from the lack of specialized hardware. It also suffers from possible malicious user interaction, as only the user has control of both smartphone and possibly the sensed environment. Data quantity revolves around reaching a critical user mass. It also revolves around keeping users engaged even though participatory sensing applications impose time and battery costs. Other solutions that have been proposed in the past, e.g. NoiseTube [6], do not sufficiently tackle these challenges.

At last years Phonesense we introduced Noisemap and described how we can increase data quality [10]. We reported our frequency correction mechanism build to mitigate poor microphones. This year we want to report on the next version of Noisemap[2] that focuses on user engagement. We implemented a number of incentive schemes. This leads to higher data quantity. By using the right incentives it will also lead to higher data quality. Most incentive schemes presented here are known from other applications such as games or mobile social networks. They have not been used in participatory sensing.

To evaluate the effect of different incentive schemes we

[2]Freely available: `https://play.google.com/store/apps/details?id=de.tudarmstadt.tk.noisemap`

have conducted a user study. Three different incentive levels were given to different groups. The results show an increase from 402 to 3,357 measurements per user from the lowest to the highest incentive level. Time spent with the application was also longer and the distance covered while measuring increased significantly.

2. RELATED WORK

Participatory sensing describes the basic concept of using a mobile device, e.g. smartphone, as a mobile sensor node [1]. Each user can participate in this mobile sensor network.

The concept has been used successfully for different applications, e.g. characterizing people movement [11], health [8] and many others. An exhaustive overview over participatory sensing applications is given in [2]. Participatory sensing is also used to build noise maps. Most notable is NoiseTube [6] developed by Matthias Stevens and Ellie D'Hondt and embedded in the Brussense project.

Noisetube shares a lot of properties with Noisemap in that it uses software calibration to enhance the measurement and is available for the Android platform. What they are missing is the frequency correction [10] and any incentive mechanism to really hit critical mass.

Incentive mechanisms have also been considered for participatory sensing. The work by Musthag et al. [7] focuses on deploying monetary micro-incentives for studies on Android devices. Other works also focus on economic models for user participation [5]. In Noisemap we try to use gamification without any monetary incentive to increase the amount of participating users as well as there engagement.

3. NOISEMAP

Noisemap is designed in order to transform a smartphone into a noisemeter. The application will return a sound pressure level (dbSPL) by sampling the microphone. Now this sampling will only return decibels relative to full scale (dbFS). dbFS measures the amplitude levels in a digital system by assigning 0 dbFS to the maximum possible digital level. All other levels are measured relative to this maximum level and negative. To translate between dbFS and dbSPL each smartphone needs to be calibrated. We use a multi-point calibration combined with frequency correction to calibrate phones for Noisemap. Afterwards we combine several measurements by calculating the long-term equivalent (L_{eq}). The L_{eq} value is sent to the da_sense urban management platform [3] and displayed to the user. All of this is needed to ensure *data quality* and we reported on our calibration scheme and a first version of Noisemap at last year's Phonesense [10].

The challenge that remains is *data quantity*. Participatory sensing is a powerful idea only if enough users participate. This is especially true for environmental data as the sampling area is measured in cities, states or countries. Noisemap has thus been redesigned to improve participation and increase data quantity. In this paper we want to report on the multi-tier incentive schemes employed in Noisemap.

The focus of Noisemap has shifted from a pure measurement tool towards a immersive sensing experience. This is reflected by the redesign.

[3] `http://www.da-sense.de`

The old design was dominated by a technical look and feel (cmp Fig. 2a). The new design features six tabs and only one of them is dedicated to measuring sound pressure (cmp Fig. 2b). The dedicated measurements tab will open a new dialog asking the user to create a new measurements series. He can choose a name and if he wants to share the measurements publicly (cmp. Fig. 2c). The new measurement screen is reduced to the necessary amount of information. This enabled us to introduce new features such as tagging (cmp. Fig. 2d). While technically interested users might miss some information from the old screen it is much easier to comprehend for the majority of users.

Four of the six tabs available at the home screen are dedicated to user incentives. These incentives can be categorized into *Internal Incentives* and *External Incentives*. We have implemented two different incentive schemes for each category. Most incentive schemes are well-known in other applications (e.g. social networks, games, etc.) but we have not yet seen all of them implemented and evaluated in any participatory sensing application. We will take a closer look at both categories in the following sections.

3.1 Internal Incentives

As a user gets more experienced with an application he demands progress. The application must reflect his experience and set new goals to achieve. We call this category of incentive schemes *Internal Incentives*. The urge for progress and to improve our skills is what drives these incentive schemes.

In Noisemap we have implemented this in two tabs: *Statistics* and *Achievements*.

Diving into Statistics, a user gets complete feedback on his measurement history (cmp. Figs. 3a and 3b). How many measurements were taken, how much time was spent with the application. It even features a scale reflecting at what time the application is used. By looking at his history a user can evaluate the time and effort put into Noisemap.

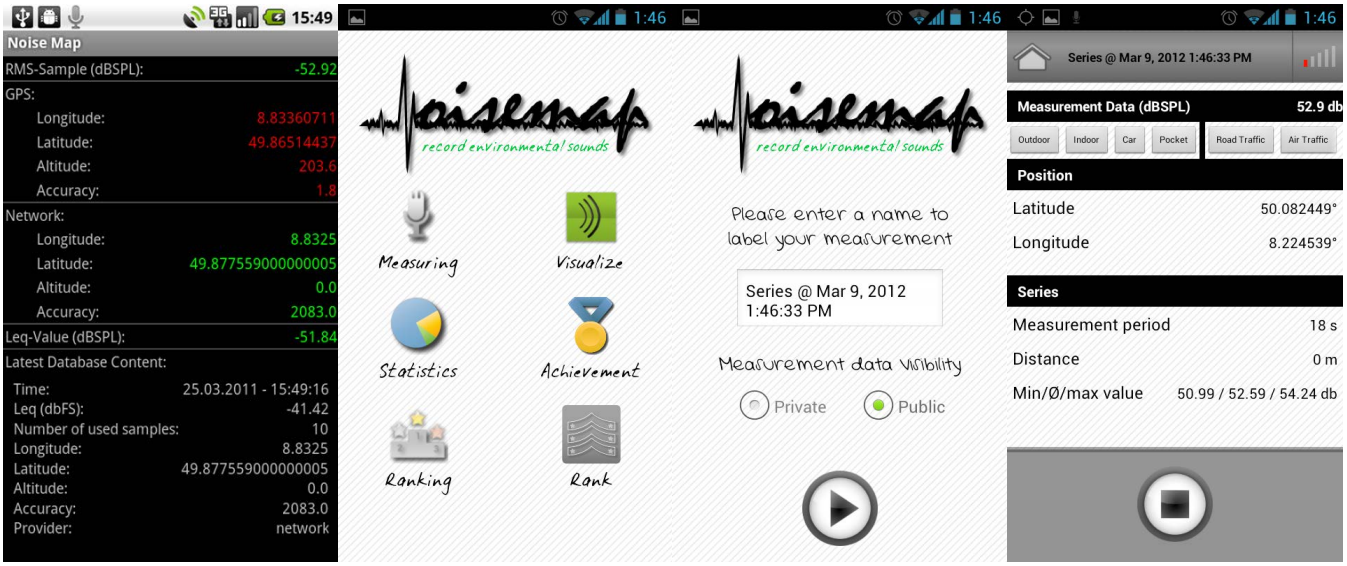
Statistics do not automatically set new goals. This is done by including Achievements (cmp. Figs. 3c and 3d). Looking at an unlocked achievement will give the same feeling of progress as with statistics. The next achievement level will be the new goal automatically set by the application. As with most achievement systems each new level is harder to reach. Now achievements can also be used to increase data quality. Each achievement incentivizes a certain behavior. In Noisemap the *Explorer* is unlocked by visiting a large amount of different measurement areas. The *Traveler* is unlocked by the distance covered during measurements. Both examples illustrate desired behavior. A user should measure in as many areas as possible, covering as much ground as possible. Other achievements incentivize tagging or measuring for a long time.

3.2 External Incentives

Internal incentives work by themselves without any social interaction. But another large motivator for human behavior is competition. We call this an *External Incentive*. The mechanism works because a user can compare his performance to other users.

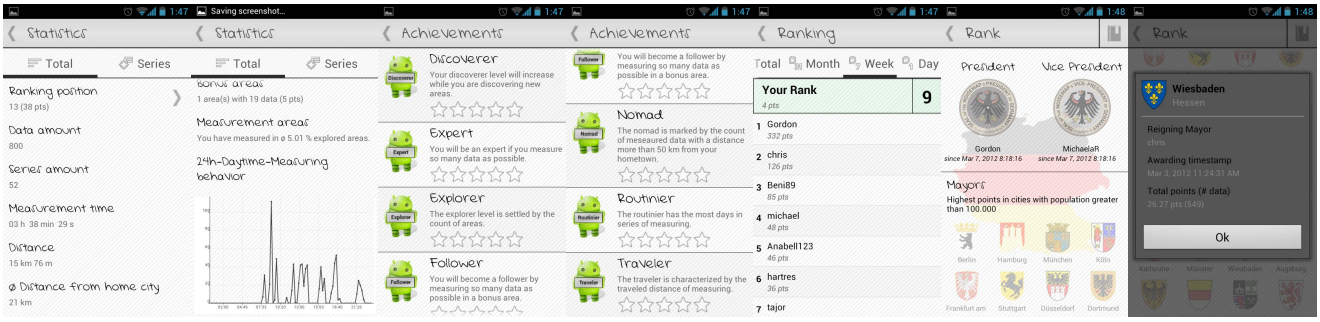
We have implemented two different tabs with external incentives: *Ranking* and *Rank*.

Ranking (cmp. Fig. 3e) is pretty straightforward. Measuring data is rewarded by points. These points are then



(a) (b) (c) (d)

Figure 2: (a) shows the old Noisemap main screen while (b) show the new main screen and (c) and (d) the new measurement screen of Noisemap



(a) (b) (c) (d) (e) (f) (g)

Figure 3: (a) and (b) show the Statistics screen,(c) and (d) show the Achievement screen of Noisemap, (e) shows the ranking screen, while (f) and (g) show different achievable ranks

used for a global ranking of all users. The ranking is available as daily, weekly, monthly and total ranking, giving new users a chance to claim top spots fast. By weighting different aspects of a measurement we increase data quality. The points P for one user are given by the following equation:

$$P = \sum_{m \in \{measurements\}} a * e(area(m)) * accuracy(m) * bonus(m)$$

Where a is a constant factor, $e(area(m))$ is the exploration factor over the last 7 days in the area where m is located, the accuracy is the location accuracy of m and bonus is given in certain bonus areas. All factors are in $[0, 1]$. Again, like with achievements, the function can be used to motivate certain behavior. e is higher in unexplored areas and m if GPS is activated. This mechanism can be used for even more fine-grained control depending on the weighting function.

Now achievements can be external or internal incentives depending on if users can compete for them. Ranks are basically achievements (cmp. Figs. 3f and 3g) that are unique to one person. They are currently limited to Germany only, but we plan on covering North America until Phonesense in November. As of today three ranks are available. The two best users overall are awarded the rank of *President* and *Vice-president* of Noisemap (Germany). Most important and known from social networks, such as Foursquare, is the *Mayor*. The mayor is available for all cities with a population higher than 100,000 in Germany. This rank is given to the most active user in that city (cmp. Fig. 3g). Last but not least is the rank of *Conqueror*. It is awarded to the user with the most points in the most areas.

All incentive schemes are foremost to motivate users to use Noisemap and increase data quantity. But some of them also influence data quality.

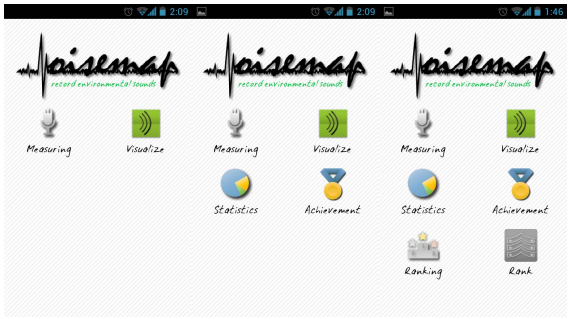
4. EVALUATION

We have been running a user study in order to evaluate

the effect of all incentive schemes. In this section, we will describe the design of the user study as well as the results.

4.1 User study design

In order to evaluate the effect of incentive schemes on user behavior we used a between-subject design. Users were divided into three groups with a slightly modified version of Noisemap: (v1) no incentives, (v2) internal incentives and (v3) all incentives.



(a) No Incentives (v1) (b) Internal Incentives (v2) (c) All Incentives (v3)

Figure 4: Three different Noisemap versions as deployed during the user study

Figure 4 illustrates the main screen as it was presented to the different groups.
(v1) No Incentives: People are only able to measure data and access it on the website (cmp. Fig. 4a).
(v2) Internal Incentives: Like (v1) with Statistics and Achievements additionally available (cmp. Fig. 4b).
(v3) All Incentives Like (v2) with Rank and Ranking also available (cmp. Fig. 4c).

In order to reach a larger user base and to be able to push updates while the study was ongoing we published Noisemap into the Play Store before starting the user study. A new user was assigned to his group uniformly at random when registering. Since some of the incentive features are only available for Germany, only German users are included in this evaluation.

4.2 Results

The user study was conducted between February 17th, 2012 and April 4th, 2012. Overall 49 users participated . The version, gender and age distributions are given in Table 1.

Version	Male	Female	Total
v1	14 (82.4 %) / 27.4	3 (17.6 %) / 22.7	17 / 26.6
v2	13 (81.3 %) / 34.7	3 (18.7 %) / 26.0	16 / 33.1
v3	14 (87.5 %) / 28.9	2 (12.5 %) / 23.0	16 / 28.1
Total	41 (83.7 %) / 30.2	8 (16.3 %) / 24.0	49 / 29.2

Table 1: Version, gender and age distributions of the participants

The geographic distribution of the users is given in Figure 5. Users from all over Germany participated, but most users were located in the Rhine-Main Metropolitan region where our university is located.

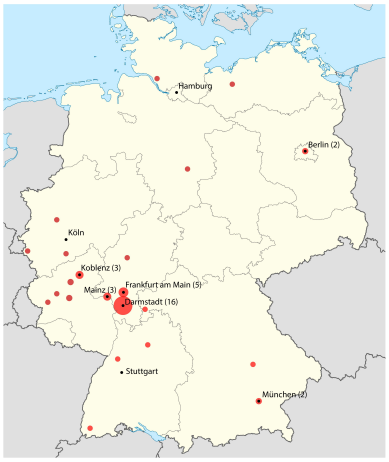


Figure 5: Geographic user distribution

In Figure 6 we take a look at the number of measurements taken by our users. The result in Figure 6a indicates that the most active users were more likely to be in group v3. The two most active users belong to group v3. The Top 10 Users consists of four users each from group v3 and v2 and two users from group v1. Please also note that the y-axis is log scaled. The effect of incentive schemes is even more obvious in Figure 6b. It presents the distribution of measurements per group per day. As engagement dwindled fast for group v1 it keeps up longer for group v2 as some incentive schemes are active. At the end though, almost all measurements were taken by group v3.

The same results are true for all other metrics measured with Noisemap as shown in Table 2.

Metrics	v1	v2	v3
Measurements	402	1,614	3,357
Time [h]	0.55	6.55	11.8
Distance [km]	12.941	34.625	153.938

Table 2: Metrics as average per user

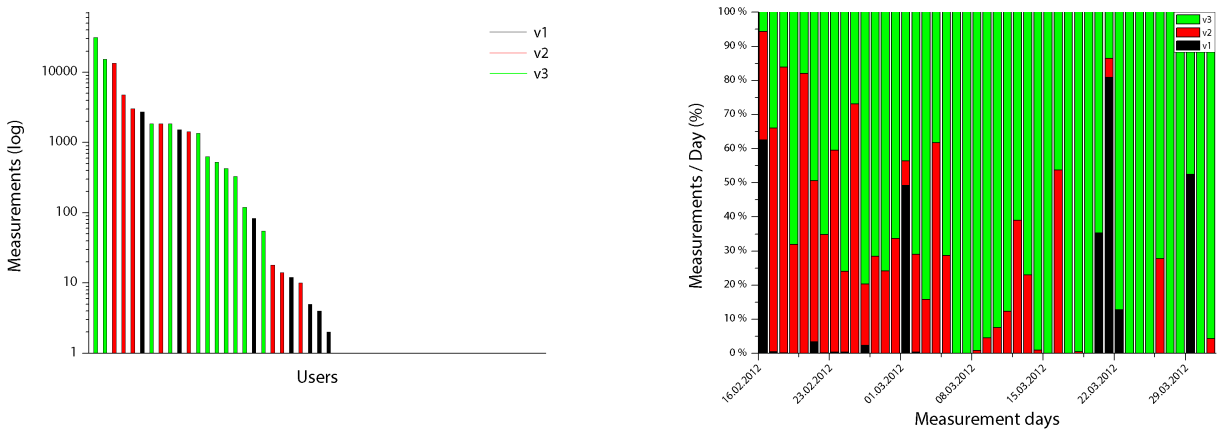
Overall as more incentive mechanisms were available, users were engaged longer in using the application. They measured more data and covered more ground.

We did also conduct a user survey at the end of the study. Only 21 users participated in this survey. While the results should thus be taken with a grain of salt, the answers provided meaningful feedback for future work.

Some of the feedback given by users:

- Achievements are a strong incentive, but the first level should be easy
- Users assign either very high or very low scores to incentive schemes
- Users in v3 are more likely to continue using Noisemap as the average user (43% to 28.5%)

As expected, users will be more engaged, if incentive schemes are used. Also, users seem to either be highly or



(a) Measurements per user

(b) Measurements per group in percent

Figure 6: Measurements taken

not at all motivated by any given scheme. Increasing the amount of incentive schemes will keep more users motivated to participate and measure data. At the end of the user study we had collected more than 85,000 measurements. A number still increasing.

5. CONCLUSION

Accurate noise maps complying with governmental regulations are costly to create and suffer from low spatial and temporal data resolution. Participatory sensing is a solution to increase the data quantity. In this paper we presented a new version of Noisemap. This version includes multiple incentive schemes to increase user engagement and in turn increase data quantity and quality. A user study conducted with 49 participants did indeed show a significant increase in user engagement. The next steps for Noisemap will be an extension of the incentive features to more countries, integration into social networks and further enhancement of the microphone calibration.

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