Noise PollutionMonitoring

ABSTRACT

Inthispaperwepresentanewapproachtomonitornoisepollutioninvolvingcitizensandbuiltuponthenotionsofparticipatory sensing and citizen science. We enable citizens tomeasuretheirpersonalexposuretonoiseintheireverydayenvironmentbyusingGPS-equippedmobilephonesasnoisesensors.Thegeo-localisedmeasuresanduser-generatedmeta-datacan be automatically sent and shared online with the public tocontributetothecollectivenoisemappingofcities.Ourprototype,calledNoiseTube,canbefoundonline[1].

CategoriesandSubjectDescriptors

H.4[**InformationSystemsApplications**]:Miscellaneous

GeneralTerms

Management,Measurement,HumanFactors,Experimentation.

Keywords

Noisepollution,citizenscience,sustainability,participatorysensing,geo-localisation,tagging,mobilephones.

1. INTRODUCTION

Noisepollutionisamajorprobleminurbanenvironments,affecting human behaviour, well-being, productivity and health[12].Excessivenoisealsohasabroaderenvironmentalimpact,forinstance it can chase animals out of their habitat or alter theirbehaviour[39].AccordingtothegreenEUpaper[12] *"Environmentalnoise,causedbytraffic,industrialandrecreational activities is one of the main local environmentalproblems in Europe and the source of an increasing number ofcomplaintsfromthepublic"*.EUexpertsestimatedthat80millionpeople suffer from noise levels considered as unacceptable, and170 million people experience serious annoyance during daytimeintheEuropeanUnion.Generallyhowever,actiontoreduceenvironmentalnoisehasalowerprioritythanotherenvironmentalproblems such as air and water pollution. With this background,there is a clear need to manage environmental noise on a nationaland local scale. Recognising this as a prime issue, the EuropeanCommissionadoptedtheEuropeanNoiseDirective[13]requiringmajorcitiestoestablishanoisemanagementpolicy.Thefirststep is to assess the current noise climate in the city by gathering real-world data and building noise maps in order to better understandtheproblemandsupportthecreationoflocalactionplans.

Numerousinternationalreports(e.g.Principle10oftheRioDeclarationonEnvironmentandDevelopment[36])have expressedtheimportanceofpublicparticipationtomovetowardssustainabledevelopment.Butoftenparticipationisonlyproposedatthedecisionmakinglevel.DuetothegrowinginfluenceofWeb 2.0 practices [23] - participation, openness and network effect;people's roles have been transformed from passive consumers ofinformationintoactiveparticipantsthankstoademocratizationofauthoring tools (e.g. wiki's, blogs) and social connection tools(e.g. social networks). But can we transfer such user-generatedcontentpracticesfromthedigitalworldtofacilitatetheiradoptionin the real world and environmental context by democratizingenvironmentalmeasurementdevicesandtherebyfullyopeningthepotentialof*citizenscience*[26]and*communitymemories*[35]?

In this paper we present the NoiseTube project[1], which follows anovelapproachtonoisepollutionmonitoringinvolvingthegeneral public. Taking inspiration from participatory sensing andusing the ubiquitous mobile phone as a platform, our goal is toinvestigate how a participatory and people-centric approach tonoise monitoring can be used to create a low-cost, open platformtomeasure,annotateandlocalizenoisepollutionasitisperceivedby the citizens themselves to inform government officials and thegeneralpublic.

Furthermore,asisthecasewithmanyissuesaffectingthesustainability of urban life, noise pollution cannot be tackled bypolicymakers alone. To manage noise pollution in cities one alsoneeds to consider the behaviour of the citizens themselves. Thefirst step towards changing such behaviour is to raise awareness.By involving them in the process of monitoring noise pollution,weattempttosupporttheraisingofawareness.

Inthenextsectionweprovideanoverviewofcurrentandalternative methods for the assessment of environmental noise.Then we describe our approach in section 3 and the prototypeNoiseTube platform we are developing in section 4. Further, insection 5 we discuss the first experiments we have conducted toassess the credibility of the sensor data. Next, in section 6 weprovideadditionalbackgroundandadiscussion.Finally,insection7 weconcludethispaper.

2. ENVIRONMENTALNOISEASSEMENT

2.1 Limitationsofthecurrentapproach

Nowadays assessments of environmental noise in urban areas aremainly carried out by officials who collect data at a sparse set oflocations, e.g. close to roads, railways, airports and industrialestates, by setting up sound level meters during a short period oftime.Propagationmodelsarethenusedtogeneratenoisemapsbyextrapolatinglocalmeasurementstowiderareas.Thispracticehas anumberoflimitations,notablyregardingtherequirementsoftheEuropeanNoiseDirective[13]-orENDforshort.

Spatio-temporal data granularity: computational models oftenproduceresultswithanunknownerrormargin,whichmayleadtoincorrect conclusions regarding caused uncomfort [33]. As statedby the EU practise guide [14], real data with high granularity inbothtimeand space isrequired. However,datacollectionatsparselocationshardlyscalestomeetsuchrequirements.Furthermore,strategicnoisemappingonlyallowsdetectinggeneral noise conditions. How can we monitor unusual local orshort-termnoisepollution?

Cost: the cost of such noise mapping campaigns is high due toneedofexpertiseandhumanresources,thedeploymentofexpensive sound level meter devices and the processing effort.This restricts cities with limited budgets from conducting suchassessments.

People noise exposure assessment: the EU practise guide [14]requires detailed assessment of the level of noise citizens areactually exposed to. However, few efforts have been done tocombine noise mapping and population data to assess the noiseexposureofcitizens[34].

Indoornoiseassessment: currentnoisemappingonlycoversenvironmental noise, i.e. outdoor noise. However, most peoplespend a significant portion of their time indoors and such indoorexposure is reported in the maps (Fig.1: area in gray with noinformation).

Figure 1. Official noise map of Paris generatedusingacomputationalmodelandmeasurementsmade at a limited number of locations andtimes. Quiet areas are coloured in green whilenoisyplacesareinpurple.Grayareasrepresent places for whichno information isavailable (e.g.inbuildings).

2.2 AlternativeApproaches

2.2.1 Wirelesssensornetworks

Recent years have seen an increasing interest in wireless sensornetworks for environmental monitoring [31] and urban sensing[7]. A wireless sensor network(WSN) is a wireless networkconsistingofspatiallydistributedautonomousdevicesusingsensors to cooperatively monitor environmental conditions, suchas temperature, sound, air pressure or air quality, at differentlocations.

Wirelesssensornetworkshavethepotentialtorevolutionizeenvironmentalassessment,notablywithregardtospatio-temporalgranularity.Ratherthanrelyingonalimitednumberofexpensive,accurate,stationaryequipment,sensing,aWSNuseslargenumbers of cheap, simple sensor devices. Sensors can be directlyembeddedintotheenvironmentandoperatecontinuously,enabling a real-time monitoring of environmental phenomena (orhumanactivities).

ArecentexampleofusingWSNsfornoisemonitoringisdiscussed in [32]. In this project noise sensors were placed atfixed locations in an urban environment. However, it remainsquestionablewhetherthismethodischeaperthantraditionalapproachesforlarge-scaledeployments.Furthermore,thesensorsarestaticandthewaythey communicateconstrainstheirplacement to certain topologies. Moreover, the involvement ofcitizensisnotconsideredinthisproject.

2.2.2 Participationofcitizens

To implement the requirements of the END [13], involvement ofcitizens is key. This is especially important with regards to localactionplans,whichoftendirectlyaffectpeoplelivingnearby.Butcitizens can also contribute in earlier phases, such as during theactualassessmentofnoisepollution.

In geography and urban planning there is a trend towards supportforsuchparticipation.Undertheflagof*participatoryGIS*[6]and*participatorymapping*newmethodologiesarebeingresearchedtobetter support the participation and involvement of citizens inprojects that are typically tackled using geographical informationsystems (GIS), such as the mapping of spatial phenomena or landuseandurbanplanning.

Someinterestingexamplesinthecontextofnoisepollutionmonitoring are [16] and [10, 21]. In the latter project researchersreached out to citizens concerned with noise pollution in theirneighbourhood. The citizens were trained, coached and equippedwithnoiselevelmeterstocreatenoisemapsaccessiblethroughanonlineGISsystem.

While such projects focus more on methodologies for reachingout to citizens and less on technical advances they have equallyinspiredourapproach.

3. APPROACH

Taking inspiration from wireless sensor networks and the trendtowards participation of citizens in mapping and urban planning,we have developed a novel approach for the monitoring of urbannoisepollution,based onmobilephones.

Concretely, in the NoiseTube project we intend to use mobilephonesasnoisesensorsandactivelyinvolvethecitizensthatcarrythem by allowing them to provide additional qualitative input(noisesourcetagging,annoyancerating,...).

In the remainder of this section we discuss and motivate thisapproachindetail.

3.1 MobilephoneasanEnvironmentalSensor

Thegrowingpopularityof*smartphones*withsignificantcomputationalpower,always-onInternetconnectivityandintegratedsensors(e.g.microphones,cameras,GPS,motionsensors) opens the door to a wide range of new applications.These devices represent a cheap but powerful WSN platform thatisreadilyavailableandwidelydeployed.Inthisperspectivemobile phones can serve as sensors which are carried by humansratherthanplacedatstaticlocations.Inadditiontocarrying aroundsensors,citizenscanalsobeinvolvedinthesensingprocess by entering qualitative inputs (e.g. tagging sources ofnoise,indicatingalevelofannoyanceandgivingcontextualinformat ion). Thanks to the aggregated mobility of users, thisapproach enables sensing coverage of large public spaces andovertime.Thisallowsthecollectionoftargetedinformationaboutth edailylifeofcitizenorforspecificlocalcampaigns.

3.1.1 Mobilesensing

Thisideaiscloselyrelatedtotheconceptof*participatorysensing*[3], which advocates the use of mobile devices to form sensornetworksthatenable public andprofessional userstogather,analyzeandsharelocalknowledge.

At the same time, people as individuals or in groups can applythese new sensing networks with a more personal focus. Theirindividual stories of everyday life can be aggregated to documentthe urban environment, fed back into a collective experience inurbanpublicspaces,enabling*people-centricsensing*[4]forpersonal,peerorpublicpurposes.

3.1.2 Democratisingnoisepollutionmeasurement

"How muchdecibelamIexposedtonow?"Thiskindofinformationiscurrentl yhardtoobtainforacitizen.Byturningsmartphonesintopersonalenvir onmentalinstruments,weareessentiallytakingadvantageofthedemo cratisation oftechnologytoachieveademocratisationofenvironmentalinformati on.

Previousparticipatorysensingprojects(e.g.airpollutionmonitoring[25])havebeenconductedinthecontextofacontrolled,localandshort-termmonitoringbyselectedvolunteersas a proof of concept. However, due to a lack of scale, the fullpotentialoftheparticipatorysensingparadigminanenvironmental context has yet to be validated empirically by realworlduse.Howwillthepracticeofpollutionmonitoringchangeifno t just few volunteers but every citizen has access to mobileenvironmental measuringdevices?

In the context of noise pollution, by turning mobile phones intonoise pollution sensors, we strongly lower the entrance barrier ofsuch environmental measurement technology. NoiseTube has thepotential to set up new kinds of experiments by enlarging thescopeofpotentialparticipants.Furthermorethegrowinginfluenceo f Web 2.0 culture [23] the notion of "user-generated content" inthe digital world will likely gain acceptance and facilitate theadoption of similar principles in a real world and environmentalcontext,fullyopeningthepotentialof*citizenscience*[2 6].

As a consequence, we expect novel mobile device applicationsandnetworkedparticipationmodelsto emerge.

3.2 Measuringpollutionattheindividuallevel

3.2.1 Personalizingenvironmentalinformation

Giving the possibility to any citizen to measure their personalnoise exposure in their daily environment could influence theirperceptions and potentially support the raising of awareness ofenvironmentalissues,thefirststageintheadoptionofnewbehaviour [30]. This is important because citizens are often –indirectly and sometimes directly; collectively and sometimesindividually – responsible for part of the noise pollution theyexperience. Changing their behaviour could thus solve a part ofthe problem. With its ubiquity, the mobile phone has alreadydemonstrateditsvalueasapersuasiontoolinseveralcases(edu cation, health and marketing [15]). The new application ofmobilephonesweproposehasabigpotentialinanenvironmental context: personalized pollution information has a bigger impactthangeneralstatistics providedby environmentalagencies tochangehabitstowardsamoresustainablelifestyle.

3.2.2 People-vs.Place-centricexposure

As described in [3], people can use this instrument in the contextof grassroots campaigns to collect pollution measures at specificlocations.Thisisthemobileextensionofthecommonpracticef orwirelesssensingnetworks[32]wherethedeploymentisstaticandthe network monitors the exposure at specific places. But the cellphone is situated in an environment, typically co-located with theuser. As a consequence, it can be also used as a tool to selfmonitortheirshort/longtermexposureandinformthecommunitya bout it. The usefulness of such people-centric data has beendemonstrated in medical projects such as [38], in which childrenwere equipped with sensors for air pollution to understand thefactorsaffectingasthma.Measuringtherealimpactofnoisepollutio n, not only from a geographical point of view, but alsothrough the people's exposure gives a new social perspective intheunderstandingofthisurbanproblemandopenspotentiallinkswit hepidemiologicalstudiesatalargerscale.

3.3 Enablingaparticipatoryculture

3.3.1 Supporting local democracy and citizen science

Theparticipatorysensingparadigmsupportslocalcampaign sandcitizen science. In this sense, the NoiseTube project is situated inthegrowingmovementoflocaldemocracy,providinginstrumentati on tools for citizens to collect fine grained data (e.g.evidence ofharmful noise exposure levels) toconvince localauthoritiesandinfluencedecisionmakingonlocalissues,without waiting for officials to gather the data [26]. We envision that theNoiseTube web platform can serve asa tool to helpexistingorganisations(e.g.groupsfocusedonwell-identifiednoisepollution problems, such as in communities close to airports) togathercredibledata.

3.3.2 SocialTranslucenceMechanismforMotivationan dAccountability

NoiseTube uses the concept of social translucence consisting inmakingparticipantsandtheiractivitiesvisibletooneanother.Therol eofsocialtranslucenceistoinform,tocreateawarenessandtoenforceac countability[11].Byenhancingthesocialperception,italsocontribute stothecoordinationofgroupsaswellasstimulatingparticipation[37].

These mechanisms also influence the level of the motivation ofthe individual and the group via social stimulation happening viasocial comparison [17], by reinforcing the perception of self-efficacyinasocialcontext[1]bydisplayingthevalueofcontribution [29]. This effect has for instance been demonstratedby [19] in the case of user-generated content on YouTube: "theproductivityincrowdsourcingexhibitsastrongpositivedependen ce on attention, measured by the number of downloads.Conversely, a lack of attention leads to a decrease in the numberofvideosuploadedandtheconsequentdropinproductivity".

3.3.3 Buildingweakandopportunisticcooperation

Eventh oughtheubiquityofmobilephonesmakesmassparticipationfeasible,a sattemptedin[4&27],itremainsquestionablehowthegeneralpublicca nbemotivatedtovoluntaryparticipate.Howtoinvolvethehiddenmajor ityofcitizenswhodonotparticipateinlocalorganizationsbutwhowant tousesuchtechnologyforpersonalpurposes?Interestingexamplesofs uchuser-generatedpractisesaretheWeb2.0serviceslikeFlickr, YouTubeorWikipedia.Aspointedoutin[5]theWeb2.0phenomenon contradicts many predictions regarding the form ofcooperationandcommunitythatwereencouragedbythepromoters of Internet. As shown in studies of bloggers [24] orWikipedia [2], the user's motivations do not fit with the twooppositeconceptions:volunteeringandbelongingtoacommunity vs. utilitarian maximising personal interest. Users generally firsthaveindividualisticmotivationswhentheybegintopublishpersonal production. But this public self-production appears todevelopagreater numberof interpersonal relations thanwasexpected, although the link between individuals is weak. Fromsuchdenseinteractionemergeopportunitiesofcooperation,transformingusers'goalsfromindividualinteresttomorecollectiveconcerns.

In our noise pollution context, the public sharing of personalexposure is an opportunity to test this new articulation betweenindividualism and altruism in a real world and environmentalcontext. Making individual noise exposure public will give theopportunitytoforgenewrelationsamongpeoplefacingtosimilarproblems.Thisway,cooperativeopportunitiescanemergenceandcollective action could be facilitated to overcome the cold starteffect and allowing the participants to assess the value of theplatforminthecontextofaveryengagingactivity.

4. NOISETUBEPLATFORM

Theprototypeconsistsofanapplicationthattheusersmustinstallontheirsmartphonesandaservercollecting, analysing andvisualisingtheinformationsentfromthephones.

4.1 Designoverview

The current prototype on the NoiseTube platform consists of anapplication which the participants must install on their mobilephonetoturnitintoasensordevice.ThemobilesensingapplicationrunsonGPS-equippedmobilephones.Thisapplicationcollectslocalinformationfromdifferentsensors(noise level, GPS coordinates, time, user input) and sent them tothe NoiseTube server. The server centralises and processes thedatasentbythephones.

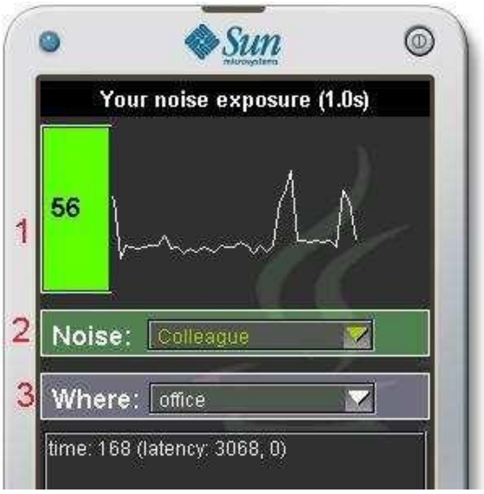

Figure2.TheMobilesensingapplication.Including3components: (1) The visualization of the loudness measuredand a color representing the danger (2) The noise tagging (3)Thetaggingofthelocation(forindoorlocationforinstance)

4.2 End-userfeatures

4.2.1 *Measuringloudnessinrealtime*

The mobile application contains a real-time signal processingalgorithm which measures the loudness level of the microphonerecording the environmental sound (at 22500 Hz, 16 bits) over 1second at a chosen interval. An A-weighting filter is then appliedtotherecordedsoundandtheequivalentsoundlevel(L_{eq})[2],measuredindB(A),iscomputed.

On top of the sensing of the loudness a real time visualization isdisplayed on the phone with the decibels. To add meaning to thisvalue it is associated with a colour that represents the health riskofthecurrentexposurelevel:<70:green(norisk);>70and<80:yellow(becareful);>80:red(risky).

4.2.2 *Tagging*

In addition to measured loudness, public noise maps often onlyprovide very limited information regarding the source or contextof noise. This sort of semantic information is vital to make suchmapsmeaningfulforend-users.Especiallybecausetheappreciationofsoundandloudnessisasubjectivematter–i.e.theperceived annoyance (or pleasure) does not always correlate withitsloudness (see6.2).

Environmental tagging: In order to better support this we aretacklingthisproblemfromthesourcebyenablinguserstodirectlyannotatesoundmeasurementsusingthemobileapplication.Userscan specify the source of a noise (e.g.: cars, aircraft, neighbours)andgiveanannoyanceratingoranyadditionalcontextualinformationintheformoffreewords(*tags*).

*Geo-tagging:*Furthermore,the lackofindoor positioning isalsoparticularly problematic because people spend a large portion ofthe their time indoors and noise pollution has effects indoors aswell. Therefore we allow users to describe their location usingpre-configured ("favourite") place tags (such as "home", "work",the name of the subway station, ...), as an alternative for GPS-positioning.Thankstothisgeo-taggingfeaturewecanreconstructthe geo-coordinates afterwards notably for indoor locations (cf.subwaynoisemapinfigure3).

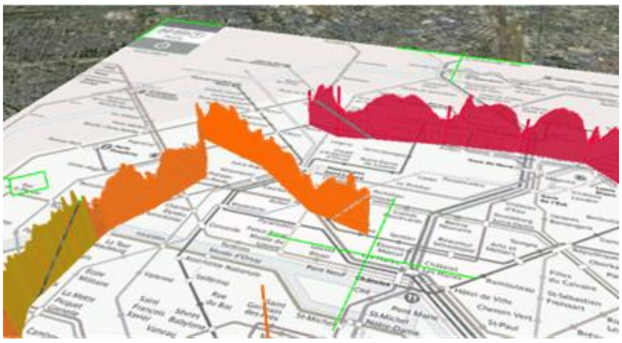

Figure 3. Noise map of two subway lines (indoor location)reconstructed thanks to the geo-tagging feature in the mobilesensingapplication

4.2.3 *VisualisingNoiseMaps*

Once the measured data is sent the server, any user can see hisowncontributionsorexposuresbygoingtotheNoiseTubewebsiteandvisualizethemonamapthankstoGoogleEarth.A

[2]L_{eq}isthestandardloudnessmeasurerequiredbytheEND[13].

collectivenoisemapisalsopubliclyavailable.Thismapisconstructedb yaggregatingallthesharedmeasurementbythe participants.Eachmapcanshowalayeroftagsenteredbyparticipants to add context and meaning to the loudness data. Arealtimemonitoringoftheloudnessreadingsofallparticipantsisalso available.

Figure 4. Visualisation with Google Earth. On the left, thecollective noise map generated by all the measures. On theright, a real time visualization of the collective noise exposureexperienceoftheparticipants

4.2.4 Makingvisibleuser'smeasuresinexistingsoci al networksecosystem

Asmentionedbeforewehaveattemptedtodevelopfeaturesrelatedtoth econceptofsocialtranslucencetomotivateandcreateaccountabilityint hecommunity.Inspiredbytheconceptofblogswedevelopedtheideaof an*Elog*,or“EnvironmentalLog”.Inournoisepollutioncontext,anElo gwouldenableindividualstoshow their life through their current noise exposure or their contributions to the noise monitoring of their city. Thanks to thispublicprofilewealsoattempttosupportopportunisticconnectiona ndinteractionamongpeoplefacingsimilarproblemsandenvironment s orleadingsimilarlives.

We also provide a way to let users embed this as a web widgetintotheirpersonalwebpagesorintotheirprofilesinsocialnetwo rk ecosystems (e.g. Facebook) to enable each user to makeit visible to their friends or to any audience. By making this datapublic, and thus also their commitmentto environmental andcitizenshipvalues,theyareimplicitlyencouragedtobuild/maintai nthiscomponentoftheirpublicidentities.

Atagloballevel,theuseofthenetworkeffecttospreadinformation through social relationship provides a simple andefficient way to raise awareness about noise exposure issues andattractnewpotentialusers.

4.2.5 WebAPItoaccesspublicdata

Currently, raw measurement data on environmental phenomenasuch as noise is generally not directly accessible for the public orscientists,limiting exploitationby third-parties.TheECdirective [13]onlyrequiresawebuserinterfacetoincreasetheaccessibilityofnois emapsforthe public. However, to avoidcreating aninaccessible information silo we want to go further than that.Therefore,theNoiseTubeplatformexposesasimpleweb APIforpublishing or accessing data. Using this API third parties such asscientistsordeveloperscanuseindividualorcollectivenoise exposuredatatocreatewebmash-upsoranalysedataforscientificpurposes.

4.2.6Dataownership&Privacy

Auserisnotalwaysacontributor.Heorsheisfreetoputornot hisorher measuresinthepublicdomainsotheycanbeusedforascientific purpose or to build a collective noise map. The userowns his/her data. Thus, for each session of measurement, or bydefault, he can decide to make his measures public and thuscontributeornottothecollectivenoisemapping.

4.3 Implementation

The current version of the mobile application was written in Javaand is aimed primarily at smart phones running the Symbian/S60operatingsystem.TheprogramwasmainlytestedonaNo kiaN958GB smart phone. Although untested, many other phone brands[3]and models are supported as well, as long as the device supportstheJavaJ2MEplatform,withmultimediaandlocalisationext ensions[4]. A GPS receiver (built-in or an external unit that isconnectedviaBluetooth)isneededtolocalisemeasures.

The server runs a web site where the users can visualise this dataon maps. The server component is implemented using Ruby onRails,MySQL,GoogleMapsandGoogleEarth.

5. DATACREDIBILITY

A fundamental issue of low-cost sensing is the credibility of thegatheredmeasurements.Thereforewemustevaluatethecorrectnes softhesensordatageneratedusingthemobileapplication.

5.1 MobilephoneasSoundLevelMeter

Without proper calibration, sensor devices produce data that maynotbeusefulorcaneven bemisleading.

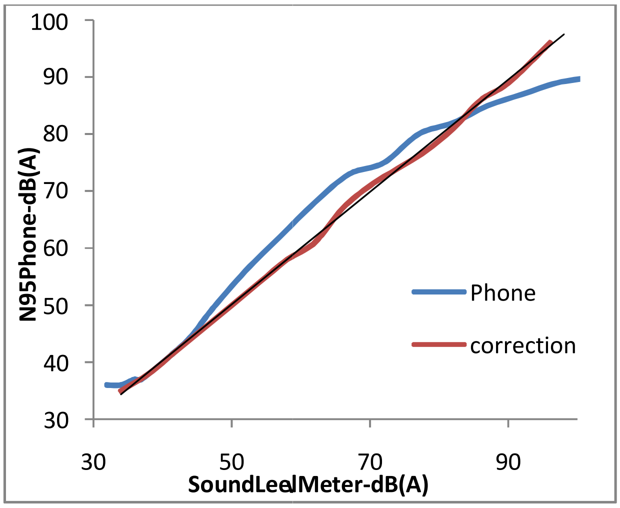

Figure5.Blueline:loudness(L_{eq})measuredbyouralgorithmusing thebuilt-inmicrophoneoftheNokiaN958GBcompared to a sound level meter in. Red line: results once weappliedapost-processingcorrectionfunction.

Experimentation has been conducted to measure the precision ofthemeasureofthe loudnesscomputedwithamobilephone

[3]InitialtestswithSony-Ericssonphonesareunderway.
[4]TobeexactthephoneshouldhavesupportforJavaJ2ME profileCLDCv1.1withMIDPv2.0(ornewer),JSR-179(LocationAPI)andJSR-135(MobileMediaAPI).

compared to a sound level meter[5]. We generated a pink noise atdifferent levels of decibels (every 5 dB, from 30 to 105) andmeasured the results with our implementation on the Nokia N958GBhandset.Theproducedcurve,thebluelineinfigure5 onthepreviouspage,showstheresponseofthemicrophonecomparedto asoundlevelmeter.Accordingtothisresultthisparticularhandset has the capacity to be used as a sound level meter in theinterval [35, 100] due to the bijectivity of the curve. After usingthe inverse function as a post processing corrector we obtainedgoodresultswithafinalprecisionof+/-3db(redline).

5.2 Positioningaccuracy

UsingtheNokiaN958GBwithitsbuilt-inGPSchipanacceptable level of positioning accuracy in outdoor situations canbeachieved.Errorsarerarelybiggerthan30meters,whichisstillgoodenoughtolocalisenoisesourceswithinaspecificneighbourhood or street. When using an external GPS receiver[6]positioning accuracy can be slightly improved. Using an externalreceiver also has the added benefit that the phone's battery life isless effected compared to using a built-in GPS chip. However, inboth cases indoor positioning is virtually impossible. This is agenerallimitationoftheGPSsystem.

6. DISCUSSIONANDFUTUREWORK

Democratisation of technologies such as NoiseTube will bringnew applications and new questions for the participatory sensingparadigm.

6.1 Rolesofcitizens

Howtosustainahuman networkatalargerscaleandforalongertime than a local and short-term experimentation or campaign?Howtodesignanetworkmixinghumansandmachinestomonitorenvironmentalresources?Asfarasweknow,thesequestionshavenot beentackledyet by the currentresearchonparticipatorysensing due to the small amount of participants and so the lack ofcomplex structures. No explicit network topology has been usedfor the experimentation except for the basic ‘star’ topology: eachparticipantcollectsandsendsinformationtoacentralpointwherethedataisanalyzedbyamachine.Butfurtherinvestigationcouldtakeadvantageofsocialrelationships,sharedinterestsorreputation(expert/scientist)amongtheparticipantsasacomponent of the problem of data/analysis credibility by usingthemnotonlyassensorsbutalsoasfiltersorregulators.

6.2 Beyondnoiseevaluation,soundscapeassessment

The subjective evaluation of sound in urban environments is acomplexfusionofmanyfactors.Therefore,therearemanyresearch areas involved in trying to understand noise pollutionfrom a subjective point of view, ranging from (psycho-)acousticsto cognitive research and sociology. Several studies have shownthatacousticsalonecanonlyexplainpartofthesubjectiveevaluation of soundscapes [9, 28]. Besides the widely deployedA-weighted sound pressure levels in noise annoyance research,these studies prove the importance of the meaning of sound innoise annoyance. However, the contributions of the semantics ofthe sound in its evaluation have been studied in experimentalsettingsmostly.Asaconsequence,otherimportantaspectsinthe experience of sound perception, such as the visual contribution,are underexposed. For example, [40] found that environmentalfactors suchas temperature, windandsunshine influence theevaluationofasoundscape.Democratisingnoisepollutionmeasurements provides a way to gather a most complete pictureof the subjective experience, since it can incorporate acousticmeasurementsaswellassubjectiveassessments.

6.3 Userfeedbackandawareness

Theuserexperience,especiallywiththemobilephoneapplication,iscrucialtomotivateuserstocontribute.Eventhoughthe current version allows users to visualize noise exposure inreal-time,wewouldliketoimprovethefeedbackbygivinginteresting insights coming from the collective experience, e.g. amap to highlight unusual pollution from measured by nearbyparticipants,inordertosupportlocaldecision-making.Furthermore, we are planning to develop more features related tosocial translucence to sustain the motivation, the accountabilityandparticipation,botharethekeyaspectsofsuchapproach.

6.4 Datacredibilityatthecollectivelevel

Untilnowwehavefocussedonthecredibilityofthemeasurementsmadebyindividualsensors(microphones).However, once a collective collection of noise data is underwaywewillalsoneedtodealwithdatacredibilityamongusers,e.g.incase of contradictory measurements. This will affect the wayaggregate,analyseandfiltermeasurements.

7. CONCLUSION

InthispaperwepresentedNoiseTube,aprojectaimedatdeveloping a participative noise pollution monitoring network toenablecitizensaswellasgovernmentalbodiesandnon-governmental organisations to gain awareness of and insight intotheproblemofurbannoisepollutionanditssocialimplications.

Wediscussedourapproachandthesupportingrationaleaswellasa prototype implementation. While this project is still in an earlystageweareplanningtoopenupafirstpublicexperimentsoontoevaluateuserexperiencesandparticipation,aswellasthecredibility of the generated noise maps compared to traditionalones.

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