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USE OF REMOTE SENSING DATA IN NOISE MAPPING – A CASE STUDY FOR LEICESTER, UK

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Abstract

The recent European Directive on the Assessment and Management of Environmental Noise [1] has engendered the requirement for EU member states to undertake noise mapping for major land transport routes and within agglomerations. It is intended that such mapping will support the introduction of policies or “action plans” to ameliorate noise issues in excessively loud locations, whilst also preserving existing quiet areas. One of the key obstacles to mapping is the acquisition of necessary data, such as traffic intensities, fleet characteristics, building geometries etc., with the required accuracy, spatial coverage and resolution. Remote sensing techniques, such as photogrammetry, RADAR (RAdio Detection And Ranging) or LiDAR (LIght Detection And Ranging) have for a long time provided the capability to describe the urban form, and it is suggested that these techniques may provide an adequate solution for noise mapping. This paper describes a method of creating 3-D building descriptions from LiDAR data. These descriptions have been used in a noise mapping application for the City of Leicester, UK. Attention in the paper is focused on two areas of the city; a sub-urban transport corridor, and a more central, mixed-use area, with each possessing predominantly different building characteristics. The noise maps produced from LiDAR generated building geometries are compared against similar maps produced by photogrammetry, from third-party stereoscopic aerial photography, and also the use of default building heights. The results are explored using both difference mapping and descriptive statistics. Conclusions are drawn with respect to future improvements to the LiDAR processing algorithm, the handling and manipulation of bulk data sets and the observed differences that occur within the final maps of weekday L_{DEN} levels.

INTRODUCTION

The task of producing a noise map for a large urban agglomeration presents a number of challenges to the acoustician. Aside from the fact that producing noise maps is generally time-consuming and computationally intensive, the single, most difficult problem that remains is the production, acquisition or management of large volumes of input data of sufficiently high quality to provide statistically useful results.

Starting from scratch, with direct survey of building properties, in order to fulfil the requirements of the European Noise Directive (END) [1] would be prohibitively expensive. Therefore, there is increased demand across the European Union for the provision of default datasets that may be used in the absence of other available data. The re-use of existing datasets available to Local or National Authorities; and the bulk acquisition of data through remote sensing technologies are two possibilities.

Building height information typically plays a dual role, for noise mapping as well as exposure modelling. Firstly, it is used in determining reflecting or screening effects on sound propagation paths. Secondly, height information may be used in estimating the exposed population in the absence of more detailed census information, by enabling the allocation of population to specific buildings through surface area or volume calculations.

The work presented within this paper concentrates primarily on the former aspect and will examine the effects of utilising differing building datasets during the generation of noise maps for selected areas of the City of Leicester, UK. These datasets differ in the precise methodology used to assign height information to building footprint vectors to extrude building blocks.

Three source datasets for building height are considered: default value of height, based on knowledge of the locale; extraction of height information using photogrammetric methods; and processing of LiDAR information. Discussion is made of the data source, capture and processing methodologies for each of the datasets. Noise difference mapping is then performed with the intention of establishing the spatial location and magnitude of any variations that arise.

METHODOLOGY

Software and Modelling Assumptions

The software used for noise mapping was the Institute for Transport Studies' (ITS) in-house program, AVTUNE (AirViro-Based, Traffic and Urban Noise Evaluator), which was previously developed for use by LCC during the EU 5th Framework HEAVEN (Healthier Environment through the Abatement of Vehicle Emissions and Noise) project [2]. The following model properties were used in the production of all noise maps:

- An implementation of the French XPS 31-133 standard [3] was used to calculate octave-band emissions for weekday traffic, and assuming bituminous road surfaces.
- The ISO 9613-2 methodology [4] was used for propagation. Source-receiver ray geometry was generated using inverse ray-tracing.
- Receivers were assumed to be downwind of sources. Atmospheric absorption was applied in accordance with ISO 9613-1 [5] using annual meteorological

parameters derived from Leicester and UK data. All receivers were positioned at a height of 4m above ground, with a 10m horizontal grid spacing.

Input Datasets (Non-building)

In order to fulfil their obligations to model and monitor local air-quality, Leicester City Council (LCC) invested in an Airviro Air-Quality Management System [6]. The Leicester Airviro system contains extensive traffic flow, road network and fleet composition information, derived both from traffic modelling and direct on-street data collection. 24-hour, weekday flow profile information was obtained from the Airviro system for mapping.

Also available was a LiDAR Digital Terrain Model (DTM), in the sub-sampled form of a 10m horizontal resolution grid file. This dataset had been purchased previously by LCC from Infoterra Ltd at the original source horizontal resolution of 1m [7]. Mainly roads (and building features) were draped directly onto the DTM. Some roads required smoothing and manual editing in order to eliminate exaggerated elevation features or add elevated sections. It was assumed that the ground surface was 50% acoustically absorbent and 50% reflective.

Building Datasets

Alongside the DTM dataset, LCC also purchased 1m resolution LiDAR Digital Elevation Model (DEM) data for the entire city, and photogrammetric building data for two sub-areas, shown in Figure 1.

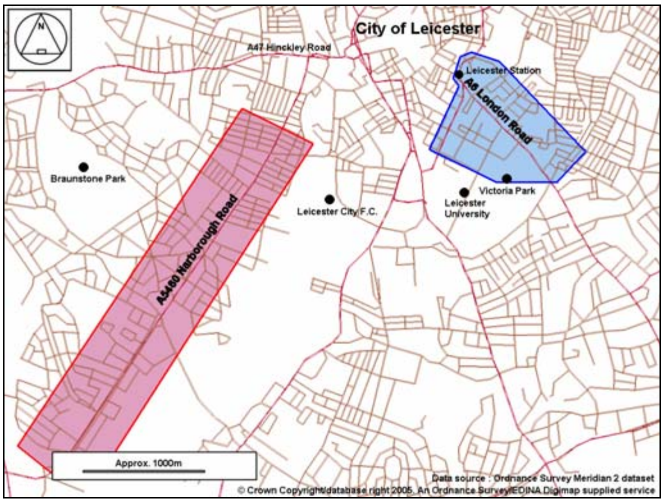

Figure 1 – Extents of purchased photogrammetric data within Leicester

The eastern area centres on the A6 London Road and contains a mixture of commercial and residential buildings, many used by the University of Leicester. The western area encompasses the A5460 Narborough Road corridor, a main radial route running from the M1 motorway to the city centre. The corridor is mainly bordered by two-storey, semi-detached residential properties.

Generation of building heights

Given the availability of the above datasets, and access to UK Ordnance Survey (OS) mapping through the EDINA Digimap service [8], the following three methodologies were selected to attribute heights to OS Land-Line^{TM} [9] polygons. Note, the Land-Line^{TM} dataset is now being superseded by the OS MasterMap^{TM} [10] digital map data.

1. Based on prior knowledge of the study areas, their dominant building types and advice found in WG-AEN's *"Good Practice Guide"* [11], default heights were assigned to all buildings in a particular area. Respectively, values of 8m for London Road and 6m for Narborough Road were selected.
2. The photogrammetry was based on the extraction of specified features from 1:10,000 scale stereoscopic coverage aerial photography, achieving a horizontal accuracy of (RMSE) of 1.0m, and a vertical accuracy (RMSE) of 0.5m. The original specification of the photogrammetric data excluded features of less than $4m^2$ plan area. Features of <2m height difference to neighbouring objects were merged. Heights were specified as being the minimum eave level above the adjacent terrain, rather than highest point within the object, subject to a 2m minimum height. OS Land-Line^{TM} data was overlaid with the photogrammetric shapes in a GIS system and common areas identified. Height attributes were then copied over into the OS Land-Line^{TM} layer, based on polygon intersections. Results were checked manually, with some merging or splitting of polygons required, leading to reassignment of heights.
3. An automatic height extraction algorithm was developed to process the LiDAR DEM data, using the OS Land-Line^{TM} data as a filter to identify building feature edges. The DEM data consists of a grid of heights above mean sea level, including both man-made structures and vegetation – hence the need for a filter to "clean" the grid prior to use in noise modelling. The LiDAR DEM data has a horizontal resolution of 1m, with vertical accuracy of points stated as being of the order of ±0.15m (Infoterra, 2005). The extraction algorithm is outlined below.

The LiDAR extraction algorithm developed is relatively straightforward, being comprised of three main steps. For each building in the OS Land-Line^{TM} data set, the vector chain describing the building outline is used to create a list of pixels in the LiDAR DEM data that correspond to the boundary of the building. All data points within 4 pixels of this boundary are used to determine the height: each boundary pixel becomes the centre of a 9x9 square of pixels that go into the final height calculation.

Secondly, the data points used to determine the height are divided into *interior* and *exterior* points in the obvious fashion, with the boundary pixels counting as *interior*. The elevation data points for each region are binned with size 0.1m. The original scheme simply used the mode for the exterior region to represent the ground elevation, the mode of the interior as the roof elevation (both elevations being height above sea level), and the difference as the desired height of the building. In practice this occasionally gave incorrect results, usually due to an isolated ‘spike’ in the elevation profile providing an elevations value far away from the majority of values.

The final step was to create a smoothing algorithm by allocating a score for each elevation bin as the sum of its number of entries, 0.8x the entries in the neighbouring bins, and 0.2x the entries in the two next nearest bins. This in effect eliminates spikes far from the ‘typical’ elevation of a building, and finds the mode from amongst the ‘typical’ values.

When the algorithm returned a building height of under 2m, the height was reset to zero. Such cases were examined separately, and generally attributed to either mismatches due to the OS LandLine™ and LiDAR datasets being captured at different time frames, leading to features existing in one dataset but not the other, or to instances where the OS LandLine™ building outline was completely enclosed by other buildings so that there was no actual *ground level* present. Some of the latter features were suspected not to be building features at all, but artefacts remaining from the conversion of the LandLine™ tiles to the GIS format used. However, there were sufficiently few cases of both types to allow manual case-by-case examination in order to assign height values, or remove features. Note, OS MasterMap™ data provides each map feature a unique TOpographical IDentifier (TOID), and provides update information, which should aid the elimination of such problems.

RESULTS

Building heights

Table 1 summarises the building polygons and their height values, as generated for the two study areas, from the three datasets.

Table 1 – Summary of building height datasets

Site	Dataset	# Valid[1]	Mean, m	St.Dev, m	Min, m	Max, m
London Rd.	Default	2586	8.0	N/A	N/A	N/A
	Photogram.	2586	6.9	3.8	2.0	78.5
	LiDAR	2557	8.1	4.1	0.0	78.1
Narborough Rd.	Default	2193	6.0	N/A	N/A	N/A
	Photogram.	2193	4.6	1.31	2.0	21.9
	LiDAR	2184	5.7	1.55	0.0	20.0

(1) # Valid = number of extruded building polygons with height of >2.0m assigned.

From Table 1, the default height values selected appear reasonable. Initial regression analysis of all LiDAR heights versus all photogrammetric heights revealed fair correlations between these parameters for both areas (R^2 = 0.61 for London Road and 0.52 for Narborough Road, respectively). It was noted however that both regressions consisted mainly of a dense cluster of values at the 5 – 10m height associated with residential properties, with few buildings over 12m. R^2 values for subsets of the data (0-6m, 6-12m, 12+m height bins) were: 0.21, 0.08, 0.64 for London Road and 0.48, 0.23, N/A for Narborough Road, respectively. There were only 3 buildings above 12m in height in the Narborough Road area. Surprisingly the correlation was better in the 0-6m building height range than in the 6-12m range. This is probably due to the fact that the buildings in the lower range are predominantly either 3 or 6m high (one or two storeys), while the distribution of building heights in the 6-12m range is more continuous.

Noise parameters

For each of the two study areas, using the above building datasets, 24 maps of weekday $L_{Aeq,\ 1\text{-hour}}$ levels were produced. Individual maps were then combined using the equation contained within Annex I of the END to produce weekday, short-term L_{DEN} values. Values are termed as L_{DEN} (default), L_{DEN} (photo.) and L_{DEN} (LiDAR) depending on the parent building dataset. Difference maps were plotted using the centre grid values. A sample map, plotting L_{DEN} (default) - L_{DEN} (LiDAR) differences is presented below as Figure 2. Buildings are coloured with respect to the difference between the LiDAR height and the default height. Road links are scaled with respect to total daily flow (maximum 32000veh/day on Narborough Road).

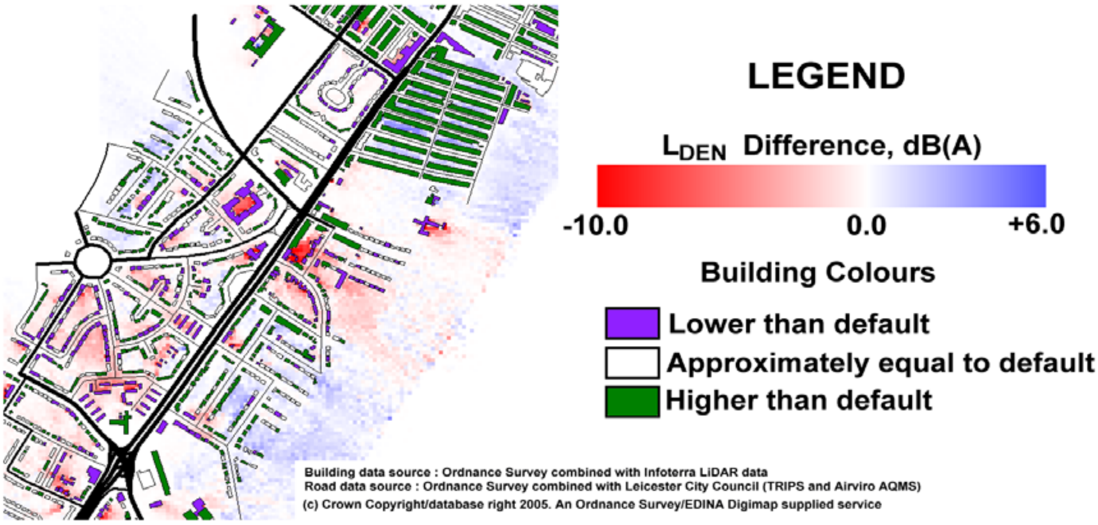

Figure 2 – Sample difference map for a section of Narborough Road area

Figure 3 displays the results obtained for the London Road area. The left-hand side diagrams plot the L_{DEN} difference levels between data sets against the initial L_{DEN} calculated when using default data. The mean difference and ±1 standard deviation are plotted, based on 2.5dB(A) bins. As would be expected, the lack of influence of building height on direct and reflected ray paths (i.e. to roadside receivers) may clearly be seen, with greater scatter in the data visible for longer paths or those undergoing diffraction. The scatter appears greatest at around L_{DEN} of approximately 45dB(A), which may have an implication for the identification of the exact boundaries of *quiet areas* as specified in the END. The right-hand diagrams of Figure 3, plot the frequency distributions of the differences in noise level. Note that a logarithmic scale has been used for the frequency (y) axis.

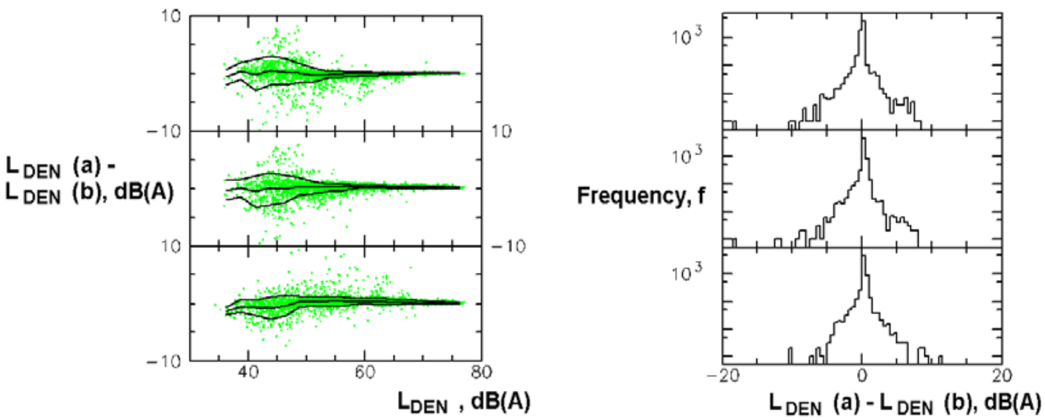

Figure 3: Differences between noise map values in dB(A) for the London Road Area, given the three methods of determining building heights. Top: a = L_{DEN} (default), b=L_{DEN}(LiDAR) , Middle: a=L_{DEN} (default),b=L_{DEN}(photo.), Bottom: a=L_{DEN} (LiDAR), b=L_{DEN}(photo.)

Table 2 summaries the differences in L_{DEN} level calculated for both study areas. Note that whilst the absolute range of differences are large, caused by instances where a particular building was present or absent in the defined datasets, the vast majority of differences are relatively small.

Table 2: Summary of differences in calculated weekday L_{DEN} values (all values dB(A))

Site	L_{DEN} value	# Valid[(1)]	Mean	St.Dev	Min	Max
London Rd.	Default – LiDAR	6461	+0.03	0.92	-18.4	+8.3
	Def – Photo.	6464	+0.23	0.89	-18.3	+7.6
	LiDAR – Photo.	6497	+0.28	0.78	-16.4	+11.5
Narborough Rd.	Default – LiDAR	41708	-0.15	1.02	-20.4	+6.4
	Default – Photo.	41744	-1.01	1.55	-21.4	+4.3
	LiDAR – Photo.	42039	-0.83	1.25	-18.8	+10.5

CONCLUSIONS

A simple algorithm for automatic building height extraction from LiDAR data has been developed and applied within the context of noise mapping. The initial performance of the algorithm in generating heights is considered encouraging. Better results were achieved for more commercial areas, because they tend to possess clearly defined buildings, compared to residential areas with sloped roofs and greater coverage by vegetation.

Future work, in conjunction with Infoterra and LCC, will concentrate on moving to a solely OS MasterMap^{TM} based approach. The building description will be improved to include maximum roof height, with the ultimate goal of attempting to identify roof shape and slope, for use with appropriate wedge diffraction algorithms in insertion loss calculations. It is proposed that mechanisms for splitting OS MasterMap^{TM} polygons will also be explored, to better detail height information, whilst retaining the unique parent polygon TOID and change information (at the building detail level). Finally, further work shall also look at the assignment of residents based on census records to individual (and within individual) OS MasterMap^{TM} derived buildings, to enable an understanding of human population exposure to noise.

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