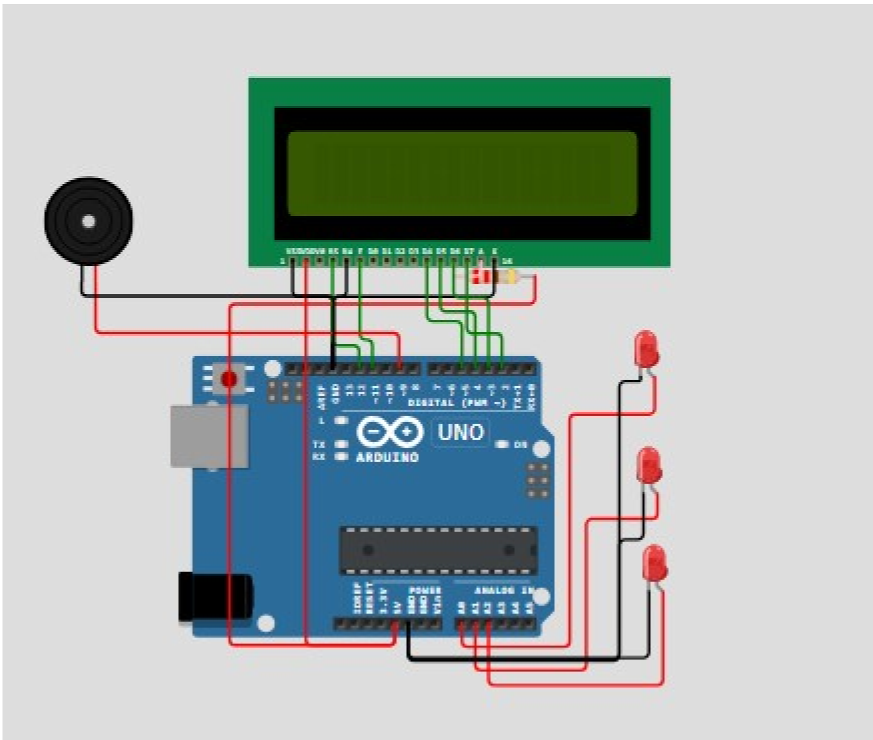
NOISE POLLUTION MONITORING USING MACHINE LEARNING

PROJECT:Noise Pollution Monitoring



Today, noise pollution is an increasing environmental stressor. Noise maps are recognised as the main tool for assessing and managing environmental noise, but their accuracy largely depends on the sampling method used. The sampling methods most commonly used by different researchers (grid, legislative road types and categorisation methods) were analysed and compared using the city of Talca (Chile) as a test case.

1. Introduction

- A recent publication by the World Health Organization points out that noise pollution, ranked second among a series of environmental stressors for their public health impact and, contrary to the trend for other environmental stressors which are declining, is actually increasing in Europe [1].
- Noise is known to have auditory and non-auditory health impacts [2]. Environmental noise causes both psychological and physiological non-auditory health effects and the evidence for the non-auditory effects is growing [3]. Specifically, road traffic is considered to be the main source of community noise pollution. The most important

non-auditory effects of traffic noise are annoyance and sleep disturbance [4,5,6,7]. Annoyance is a feeling of displeasure that can result in adverse emotions including irritability, stress, fear, and even depression [8,9,10,11,12]; it is associated with health-related quality of life [13,14,15].

2. Methods

- This study was conducted in the city of Talca (Maule region, Chile). Talca has a population of about 200,000 inhabitants (the population increases during the academic year due to the influx of university students) and is the tenth largest city in the country. The highest percentage of the active population (approximately 55%) works in the service sector, followed by the industrial sector (approximately 36%). This city does not have a historic centre and a high percentage of buildings have only one floor. The mean annual temperature and rainfall are 13 °C and 750 mm, respectively.

- Three sampling methods were analysed: the grid method [42], road types established by the Ministry of Transport and Telecommunications of Chile (MTT) [46], and the categorisation method [45]. In order to compare the uncertainties using a similar sampling time the same number of sampling points (52) was selected for each measurement method. The grid method was analysed because it is accepted in an international standard, but its applicability was not compared with the other sampling methods.

DATASET:

```
#include <LiquidCrystal.h> // include the LiquidCrystal library


const int micPin1 = A0; // define the pin for the first microphone

const int micPin2 = A1; // define the pin for the second microphone

const int micPin3 = A2; // define the pin for the third microphone

const int buzzerPin = 9; // define the pin for the buzzer

const int ledPin = 6; // define the pin for the LED

const int contrast = 50; // define the LCD contrast
```

```
LiquidCrystal lcd(12, 11, 5, 4, 3, 2); // initialize the LCD display


void setup() {
  pinMode(buzzerPin, OUTPUT); // set the buzzer pin as output
  pinMode(ledPin, OUTPUT); // set the LED pin as output
  lcd.begin(16, 2); // initialize the LCD display
  analogWrite(6,contrast); // set the LCD contrast
  Serial.begin(9600); // initialize the serial monitor
}


void loop() {
  // read the values from the microphones
  int micValue1 = analogRead(micPin1);
  int micValue2 = analogRead(micPin2);
  int micValue3 = analogRead(micPin3);


  // calculate the sound levels in dB for each microphone
  float voltage1 = micValue1 * 5.0 / 1024.0; // convert the first microphone
value to voltage (5V reference)
  float voltage2 = micValue2 * 5.0 / 1024.0; // convert the second
microphone value to voltage (5V reference)
  float voltage3 = micValue3 * 5.0 / 1024.0; // convert the third microphone
```

value to voltage (5V reference)

float dB1 = 20 * log10(voltage1/0.0063); // calculate the sound level in dB for the first microphone

float dB2 = 20 * log10(voltage2/0.0063); // calculate the sound level in dB for the second microphone

float dB3 = 20 * log10(voltage3/0.0063); // calculate the sound level in dB for the third microphone

// calculate the average sound level in dB for all microphones

float averageDB = (dB1 + dB2 + dB3) / 3;

// display the sound level on the LCD display and the serial monitor

lcd.setCursor(0, 0); // set the cursor to the first row of the LCD display

lcd.print("Sound Level: "); // print the text "Sound Level: " on the LCD display

lcd.setCursor(0, 1); // set the cursor to the second row of the LCD display

lcd.print(averageDB); // print the average sound level on the LCD display

Serial.print("Sound Level: "); // print the text "Sound Level: " on the serial monitor

Serial.println(averageDB); // print the average sound level on the serial monitor

// control the LED and the buzzer based on the sound level

```
  if (averageDB > 70) { // if the sound level is higher than 70 dB
    digitalWrite(ledPin, HIGH); // turn the LED on
    tone(buzzerPin, 1000, 500); // turn the buzzer on
  } else { // if the sound level is lower than 70 dB
    digitalWrite;
  }
}
```

2.1. Grid Method

- In the grid method, a grid is superimposed over a city map and the measurement points are located at the nodes of the square or at the nearest location when the nodes are inaccessible. The area of Talca is approximately 29 km2. A total of 35 squares with 52 sampling points were drawn on the city map using a grid square with 800 m of resolution. A similar square grid resolution has been used in previous studies [33]. Figure 1a shows the map of Talca with the grid used for this study.

Today, noise pollution is an increasing environmental stressor. Noise maps are recognised as the main tool for assessing and managing environmental noise, but their accuracy largely depends on the sampling method used. The sampling methods most commonly used by different researchers (grid, legislative road types and categorisation methods) were analysed and compared using the city of Talca (Chile) as a test case. The results show that the stratification of sound values in road categories has a significantly lower prediction error and a higher capacity for discrimination and prediction than in the legislative road types used by the Ministry of Transport and Telecommunications in Chile. Also, the use of one or another method implies significant differences in the assessment of population exposure to noise pollution. Thus, the selection of a suitable method for performing noise maps through measurements is essential to achieve an accurate assessment of the impact of noise pollution on the population.

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- Noise is known to have auditory and non-auditory health impacts [2]. Environmental noise causes both psychological and physiological non-auditory health effects and the evidence for the non-auditory effects is growing [3]. Specifically, road traffic is considered to be the main source of community noise pollution. The most important non-auditory effects of traffic noise are annoyance and sleep disturbance [4,5,6,7]. Annoyance is a feeling of displeasure that can result in adverse emotions including irritability, stress, fear, and even depression [8,9,10,11,12]; it is associated with health-related quality of life [13,14,15].

2. Methods

- This study was conducted in the city of Talca (Maule region, Chile). Talca has a population of about 200,000 inhabitants (the population increases during the academic year due to the influx of university students) and is the tenth largest city in the country. The highest percentage of the active population (approximately 55%) works in the service sector, followed by the industrial sector (approximately 36%). This city does not have a historic centre and a high percentage of buildings have only one floor. The mean annual temperature and rainfall are 13 °C and 750 mm, respectively.

- Three sampling methods were analysed: the grid method [42], road types established by the Ministry of Transport and Telecommunications of Chile (MTT) [46], and the categorisation method [45]. In order to compare the uncertainties using a similar sampling time the same number of sampling points (52) was selected for each measurement method. The grid method was analysed because it is accepted in an international standard, but its applicability was not compared with the other sampling methods.

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2.2. Road Types Established by the MTT

- The Ministry of Transport and Telecommunications of Chile (MTT) classifies urban roads according to their main function and their urban design features. However, in practice, urban characteristics, such as the width of the roads, are more relevant. Five types of roads are differentiated: highway, trunk, service, collector, and local. A similar classification has been used in recent acoustic assessment studies of cities in Chile and in other countries [27,37,38,39,40].

- The sampling points were then randomly selected along the total length of each road type taking into account two factors. First, in the types of roads with a greater length (see Figure 2), a greater number of sampling points were selected with a minimum of eight sampling points for each road type. Second, equivalent points (those points located on the same section of a street with no important intersection between them) were discarded. For this reason, only one sampling point was selected in the highway road type. Figure 1b shows the road types and locations of the sampling points: one point in highways, eight in trunk, twelve in service, eight in collector, and twenty-three in local road types.

2.3. Categorisation Method

- As previously mentioned, the categorisation method is based on the concept of street functionality, that is to say, the functionality of the streets of the city as a communication path between different parts of the city and between the city and other urban areas. In addition, other variables such as the flow of vehicles, the type of traffic, the average speed, and urban variables may have a clear relationship with functionality [47]. The streets of Talca were classified according to the definitions proposed in the categorisation method established in previous work [48].

- A strategy similar to the previous method was used to select the sampling points in each road category. Figure 1c shows the categorisation of different streets in the city and the locations of sampling points: eight points in Category 1, eight in Category 2, ten in Category 3, twelve in Category 4, and fourteen in Category 5.

2.4. Measurement Procedure

The measurements of different methods were carried out simultaneously from March to July 2015 following the ISO 1996-2 guidelines [42]. The measurements were performed on different working days and the sampling time for each measurement was 15 min. Previous studies [36,49] showed stability of the daily noise levels in the aforementioned months, and also these studies indicated that the main temporal variability of noise levels was among time-intervals within the day. At each sampling point, for each sampling strategy, at least five measurements were randomly selected in the following time-intervals: diurnal (from 07.00 to 19.00), evening (from 19.00 to 23.00), and nocturnal (from 23.00 to 07.00). A type-I sound level meter (2250 Brüel & Kjaer; Nærum, Denmark) was used with tripod and windshield and it was placed at a height of 1.5 m and at 2 m from the curb.

The A-weighted equivalent sound level (LAeq) was used to analyse the results in the present study at different time-intervals of the day. The LAeq registered in the diurnal period (from 07:00 to 19.00) and evening period (from 19.00 to 23.00) was very similar. For this reason, LAeq from 7.00 to 23.00 (Ld) was analysed. The noise descriptor Lden was calculated following the guidelines of the European Noise Directive [22]. Other relevant information (traffic flow, types of vehicles, meteorological conditions, urban variables, etc.) was also noted.

2.5. Statistical Analysis

In the acoustic assessment in Talca, the applicability of different sampling methods was analysed using the calculated noise descriptors (Ld, Ln and Lden) at each sampling point (Pij). The subscript "i" refers to the point code and the subscript "j" refers to the sampling method.

- In the grid method there are no assumptions of the location of sampling points in urban roads. However, the location of the sampling points with respect to the traffic noise source was similar in the different sampling methods. For this reason, the sound values registered in the sampling points of the grid method were used to analyse the predictive capacity of the others two sampling methods. The noise value assigned to each square (Si) was the median value of the four nodes of the square. For each square, the interquartile range was calculated from these four values. Moreover, the difference in sound levels between adjacent grid points was calculated. This difference should not be greater than 5 dB according to ISO 1996-2 [42].

- For the MTT road types and the categorisation method a similar statistic procedure was carried out. The value assigned to each road type (Ri) or road category (Ci) was the average of the sound levels measured at the sampling points (Pij). This value was the expected value for all of the other points located in the same road type or road category. The average sound value and its variability will determine whether the stratums formed by road categories or by road types present significant differences. This hypothesis was assessed using the nonparametric tests Kruskal-Wallis and Mann-Whitney U [50,51]. This hypothesis was not tested with an inferential analysis in previous studies that used a legislative road classification [27,37,38,39,40]. The Kruskal-Wallis test was used to compare all the road categories in order to identify any significant differences. When such differences were found, Mann-Whitney U tests were used to compare pairs of road categories. The Mann-Whitney U test evaluates whether two independent samples or observations come from the same distribution. To avoid any errors due to the use of data from the same population rather than randomly selected data, the Holm correction was used [52].

$$sensitivity = n^\circ\ of\ sampling\ points\ assigned\ correctly\ to\ stratum\ i n^\circ\ of\ sampling\ point\ in\ stratum\ i$$

(1)

$$non-specificity = n^\circ\ of\ sampling\ points\ assigned\ incorrectly\ to\ stratum\ i n^\circ\ of\ sampling\ point\ do\ not\ belong\ to\ stratum\ i$$

(2)

$$predictive\ value = n^\circ\ of\ sampling\ points\ assigned\ correctly\ to\ stratum\ i n^\circ\ of\ sampling\ point\ that\ ROC\ method\ includes\ in\ stratum\ i$$

(3)

After studying the functioning of both methods, the predictive capacity of each method was then analysed using the sound values of the sampling points of the other methods as controls [53,54]. The parameter used for this analysis was the prediction error (εi), which is the difference between the measured value (control value) and the predicted value. The equations used to calculate the prediction error of the MTT road types (Equation (4)), and categorisation method (Equation (5)), respectively, were as follows:

$$\varepsilon i = Pij - Ri$$

(4)

$$\varepsilon i = Pij - Ci$$

(5)

The subscript "i" refers to the sampling point code (Pi), road type code (Ri) or road category code (Ci), and the subscript "j" refers to the sampling methods in which the error is not being analysed. Next, the median prediction error obtained for each road category or road type was compared with the null value. For this, the Wilcoxon signed-rank test was applied [55]. This test determines whether the median of the prediction errors was biased. If the distribution of the prediction errors is unbiased, then a zero value will be obtained for the median.

Prediction errors of the different methods were also compared. To that end, the median absolute error of prediction (|εi|) was analysed using the Mann-Whitney test [51]. If there is no significant difference it is assumed that the sampling methods have a similar predictive capacity.

Finally, the population exposed to noise was analysed and the population annoyed by noise was estimated. The demographic data of the geographic information system of the National Statistics Institute of Chile [56] were used to analyse the population exposed to noise. Noise levels registered in the road categories or road types were assigned to populations that reside in them [54]. Internationally validated equations were used to estimate the population annoyed by noise. Thus, the percentages of annoyed (%A) and highly annoyed (%HA) population were estimated from the Lden descriptor with the following equations [57,58]:

$$\%A=0.0001795(Lden-37)^3+0.0211(Lden-37)^2+0.5353(Lden-37)$$

(6)

$$\%HA=0.0009868(Lden-42)^3-0.01436(Lden-42)^2+0.5118(Lden-42)$$

(7)

With respect to nocturnal noise, the percentages of population with little sleep disturbance (% LSD), sleep disturbance (%SD), and those who were highly sleep disturbed (%HSD) were estimated from Ln descriptor using the following equations [59]:

$$\%LSD=(-8.4)+0.16Ln+0.01081(Ln)^2$$

(8)

$$\%SD=13.8-0.85Ln+0.01670(Ln)^2$$

(9)

$$\%HSD=20.8-1.05Ln+0.01486(Ln)^2$$

(10)

3. Results

3.1. Study of the Functioning of Sampling Methods

3.1.1. Grid Method

Having calculated the sound values of Ld, Ln and Lden descriptors in the different sampling points, the sound values of the different square grids were calculated. The results are shown in Table 1. Table 1 shows that the interquartile range of sound values registered in the cells is quite high. Previous studies [33,48] reported high uncertainties in the predictive capacity of the grid squares, due to the high variability of the sound levels among nearby streets with different functionality. Therefore, if the sound differences between adjacent sampling points are analysed, 69%, 49% and 59% are higher than 5 dB for Ld, Ln and Lden descriptors, respectively.

Table 1. Median (Me) and interquartile range (IQR) of Ld, Ln and Lden descriptors registered in the square grids.

Table

3.1.2. MTT Road Types

This stratified sampling is based on the hypothesis that different strata—road types in this case—have significant differences in sound values. First, to resolve this hypothesis, a descriptive analysis through a box plot was carried out (Figure 3).

Regarding the non-specificity (%), which measures the proportion of sampling points that were not initially assigned to a given stratum, but which the ROC analysis indicates belong to that stratum, only the local road type has values lower than 10% for all the sound descriptors. The collector road type also has high non-specificity values for all the sound descriptors, although it has high sensitivity values for Ln and Lden.

Finally, with regard to the predictive values of the different road types (which represent the proportion of the sampling points that the ROC analysis assigned to the stratum that matched the road types to which they were initially assigned, relative to the total number of sampling points that the ROC analysis determined for the stratum) only the local road type has values above 80% for all the sound descriptors. The stratum predicted by the ROC analysis for local road types has a high percentage of sampling points that MTT had initially classified in this road type. However, other sampling points of local road types have high values and these points are classified in other road types according to ROC analysis. Therefore, the local road type has low sensitivity values.

3.1.3. Categorisation Method

The different road categories defined by the method are based on the assumption of having significantly different noise levels. Therefore, like the MTT road types method, a descriptive and inferential analysis was conducted to test this hypothesis. The results of the descriptive analysis are shown in Figure 5.

Table

As shown in Table 3, the Mann-Whitney U test found significant differences (p-value ≤ 0.01) among all pairs of road categories studied for all sound descriptors analysed. To corroborate the previous results, as carried out for the previous method, the classification capacity of the categorisation method was studied via ROC analysis. The results of this analysis are shown in Figure 6.

The results presented in Figure 6 show that the sensitivity of different sound descriptors is higher than 80% for all road categories (except the Ln in Category 4), and even for the Lden descriptor it is 100%. These high percentages are also obtained for the predictive value and therefore the percentages obtained in non-specificity are very low. They are lower than 5% in all sound descriptors.

These results differ from the previous method and it is therefore essential to compare the predictive capacity of both sampling methods. The results of this comparison are shown in the following section.

3.2. Predictive Capacity Analysis

In analysing the predictive capacity of the sampling methods, the sound values registered at the sampling points of the methods that were not being analysed were used.

To evaluate predictive capacity of the MTT road types, the sampling points chosen for the grid and categorisation method were used to compare the predictions of the MTT road types. All 104 sampling points evaluated in the grids and road categories could be associated with one of the road types (only one point was located in the highway road type, therefore, this road was not analysed). The sound values of these sampling points were compared with the mean value of the road type in which they were located and the prediction error was calculated using the difference between them (Equation (4)). The prediction error was analysed according to the road type where the control sampling point (Pij) was located. Table 4 shows

3.3. Calculation of Exposure Level and the Percentage of Annoyance

In the previous section the predictive capacity of sound values was analysed according to the different sampling methods. A sampling method that presents significant uncertainties of prediction will directly influence the calculation of the exposed population. Therefore, the variation in the level of exposed population and the percentage of annoyance depending on the sampling method used were analysed. In this study, the categorisation and MTT road type methods were analysed.

The results show that different road types have percentages of annoyance and sleep disturbed by noise higher than those registered in the different road categories. Those road types that register higher noise levels, and therefore higher levels of noise annoyance, are those that had a higher level of sound prediction uncertainty. The trunk and service road type have similar percentages of annoyance to Categories 2 and 3. However, in previous analysis significant problems of differentiation between these two road types were found. Furthermore, the difference in the percentages of annoyance between the local road type and Category 5 should be noted, being those with lower noise levels. These differences were also detected in the analysis of sound exposure.

4. Discussion

The variability of sound values registered in the grid squares of Talca is quite high. This result indicates a low predictive capacity of the grid method to assess the noise exposure. If the interquartile range obtained in the cells is compared with that obtained in the local road type and in Category 5 (the road type and road category with the highest variability of noise levels), more than 50% and 75% of the grids register a greater value, respectively. Indeed, the grid size is quite high; however, as stated above, in this study has been considered relevant to use the same number of sampling points in each measurement method. Following the instructions of the ISO 1996-2 [42], if intermediate grid points would be added when the sound differences between adjacent grid points were higher than 5 dB, a new sampling would have carried out with a number of similar points. However, as shown in previous studies [33], the selection of new sampling points does not guarantee a difference between adjacent points lower than 5 dB. Consequently, this method was not used in order to compare the uncertainties between different sampling methods.

The prediction errors of the categorisation method are lower than those of the MTT method for the different urban roads analysed. These differences in the prediction of sound values involve differences in the estimation of exposure levels and percentage of annoyance. According to the MTT method, 10% of the population is exposed to $L_{den} > 65$ dB, whereas this is 23% of population according to the categorisation method. Also, as shown in Figure 8, road types have percentages of annoyance and sleep disturbed by noise higher than those registered by road categories.

5. Conclusions

The selection of a suitable sampling method is essential to achieve an accurate assessment of the impact of noise pollution on the population. The grid, MTT road types and categorisation methods were analysed in the city of Talca (Chile). The major conclusions drawn from the results are as follows:

The grid squares have a high variability of sound values. This high variability leads to differences in sound values registered at adjacent points of more than 5 dB in 69%, 49% and 59% for Ld, Ln and Lden descriptors, respectively.

The MTT road types have a low percentage of sensitivity and predictive capacity (except for the collector road type for Ln and Lden that has values above 80% of sensitivity and for the local road type for all the sound descriptors that has values above 80% of predictive capacity) and a high percentage of non-specificity (except for the local road type for all the sound descriptors that has values lower than 10%). This low discrimination and predictive capacity is caused, among other factors, by the lack of significant differentiation of sound values registered in trunk and service road types and by the high variability of the sound values of the local road type.

Average sound values in the different road categories of the categorisation method have highly significant statistical differences. The road categories also have a high percentage of sensitivity (>75%) and predictive capacity (>80%) and a very low percentage of specificity (<5%). Therefore, the functional stratification of noise levels observed in European cities that were studied previously is also found in Chilean cities. These results suggest a great advance in the validity of the categorisation method because of its application in a Chilean city.

The predictive capacity of the categorisation method is higher than that of the MTT method. This difference in the predictive capacity of sound values involves differences in the estimation of exposure levels and in the percentage of annoyance. Consequently, the categorisation method is more accurate than the MTT method to assess the impact of noise pollution on the population.

Talca is a city affected by noise pollution and also by its related problems of public health of its inhabitants. The percentages of population exposed to daytime and nighttime sound levels that are harmful to health are higher than those obtained in Helsinki and Berlin. Furthermore, the percentage of exposed population to Lden > 64 dB is much higher than that obtained in the cities of Basel, Rotterdam and Thessaloniki.