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10th International Conference on Smart Cities and Green ICT Systems

Final Program and Book of Abstracts

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Design of an Urban Monitoring System for Air Quality in Smart Cities

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Motivations

• Pollution is one of the main problems faced by cities
  • increase in emissions from anthropogenic sources resulting from economic, industrial and demographic development

• High values of pollutants (e.g. atmospheric particulate matter) lead to adverse effects on the environment and human health
  • spread of respiratory, cardiovascular and neurological problems
  • connection between the spread of the Covid-19 pandemic and environmental pollution? [Setti et al., 2020] [Wu et al., 2020] [Fattorini and Regoli, 2020]

• Urban monitoring of pollutants can allow to evaluate and perform actions aimed at reducing pollution in order to safeguard citizens’ health
Overview

• This study proposes a method to design a low-cost urban air quality monitoring system that can be implemented in any small-to-medium-sized smart city

• The monitoring concerns atmospheric particulate matter (PM10 and PM2.5)

• Sensors are connected through a LoRaWAN network

• Location of the sensors are determined in two steps
  1. Analytic Hierarchy Process (AHP) multi-criteria decision-making technique
  2. Cellular Automaton model in order to ensure the best overall coverage of the polluted areas
Case study

- Santa Maria degli Angeli
  - (43°03′32″N 12°34′41″E)
  - Municipality of Assisi (Italy)
  - 8470 inhabitants

- Over the years, the area has experienced an important urban development
  - residential settlement
  - industrial activities (concentrated in the south-west area)

- LoRaWAN network consists of six sensors
Analytic Hierarchy Process (AHP)

• Analytic Hierarchy Process (AHP) is a multi-criteria decision-making technique [Saaty]

• AHP allows to assign priorities to a series of decision-making alternatives and define them on a single scale, relating also parameters that are not directly comparable

• The method is made of three steps:
  • definition of a hierarchy of the problem (final objective, criteria, alternatives)
  • for each hierarchy layer definition of the matrices of pairwise comparisons and computation of the priority vector
  • hierarchical recomposition
**Final objective**: locations of sensors for air quality monitoring

**Criteria layer**: three main sources of pollution [Samad & Vogt, 2020]
- Evaluation through a participatory process with the direct involvement of citizens (survey)

**Alternatives layer**: twelve candidates locations for the sensors
- Evaluation through a more objective method using available data
• Twelve urban sectors (A-L) identified by the three main roads axes and the other main roads
AHP: questionnaires

• Questions:
  • which is the main source of atmospheric pollution among home heating, traffic and the presence of industrial activities?
  • how much the indicated source of pollution is more decisive than the other two, expressing a value in the scale from 1 to 9?
  • subjective assessment of the air quality in the various areas of the town (polluted or clean?)

• The anonymous questionnaires were distributed to a heterogeneous sample of citizens, inhabitants of the study area, of different ages and gender

• 38 questionnaires were collected
AHP: criteria comparison

• Collected values aggregated by means of the geometric mean and approximated to the nearest integer number yielding the pairwise comparisons matrix

<table>
<thead>
<tr>
<th></th>
<th>Home heating</th>
<th>Traffic</th>
<th>Industrial activities</th>
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</thead>
<tbody>
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<tr>
<td>Traffic</td>
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<tr>
<td>Industrial activities</td>
<td>8</td>
<td>5</td>
<td>1</td>
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</table>

• Priority vector = normalized principal eigenvector

\[
\begin{pmatrix}
0.0545 \\
0.2331 \\
0.7125
\end{pmatrix}
\]

- home heating
- traffic
- Industrial activities
AHP: alternatives comparison

• **Home heating criterion**: on the basis of the population data in each sector as recorded in the Municipality database

• **Traffic criterion**: considering how each sector is enclosed by main roads

• **Industrial activities criterion**: considering the average distance of each sector from the foundry and the industrial area to the south-west of the town
## AHP: hierarchical recomposition

<table>
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<th>Ranking</th>
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<th>Traffic (0.2331)</th>
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</table>

Sensors positions as selected by AHP analysis
AHP: sensors locations

[Map with labeled points and urban sectors A-L, indicating potential sensor locations and sensors locations selected by AHP.]
Cellular automaton (CA)

- A cellular automaton is a **discrete dynamic system**
- It consists of a set of elements, called **cells**, organized in a **regular spatial grid** and taking on a **finite number of states**
- The state of each cell at a certain moment **evolves** according to a given **transition rule** depending on the present state of the cell itself and the states of the neighborhood
- The neighborhood can be defined in many ways

![Von Neumann neighborhood](image1)

![Moore neighborhood](image2)
• **Goal:** optimizing the configuration obtained with the AHP method

• **11 × 8 grid** superimposed on the study area
  - Cell dimensions 200 × 200 m

• **Two binary variables associated to each cell:**
  1. Absence (0) / presence (1) of a sensor (dynamical)
  2. Unpolluted (0) / polluted (1) area, as derived by the survey (fixed)

• **CA initialized with the sensors placed in the position determined by AHP**
CA dynamics

- At every iteration step each sensor moves in its Moore’s neighbourhood (or remains in the current position) according to a stochastic dynamics:
  - A probability is assigned to every possible movement of the sensor reflecting the coverage of the polluted areas that the movement will determine
  - The actual movement of the sensor is randomly extracted according to movements probabilities

- The new configuration is accepted if it results in an increase of global coverage, otherwise it is discarded and the system remains in the previous configuration

- The system evolves till it reaches a stable configuration...
Results

1\textsuperscript{st} step
Sensors locations resulting from AHP

Final configuration
Sensors locations resulting from CA
Outlook

• A **real** air quality monitoring system is going to be implemented in Santa Maria degli Angeli

• A **more refined optimization** of the sensors positioning, considering levels of pollution determined using not only surveys but also
  • the **measurements** detected by the sensors
  • the **epidemiological data** regarding respiratory and cardiovascular diseases associated with long-term exposure to high levels of pollution

• When the sensors will be installed and when a **significant amount of data** will have been collected the **cellular automaton step** will be run again in order to possibly improve the configuration
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