CT5134 - Assignment 1 Report
Agent & Multi-Agent Systems Applied to Air Pollution Monitoring

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1 Introduction

Air pollution has been a prevalent problem since before the Industrial Revolution, which has hazardous impacts on our health. According to the World Health Organization, air pollution is the world's largest environmental health risk [1]. It is imperative that efforts are focused on handling the problem of "Dirty Air", and monitoring the air for pollutants is an essential first step towards air quality management. Intelligent agents have been studied for decades now, with an aim to apply their intelligence in making living convenient for humans. But these agents could prove most beneficial in applications which have a non-sustainable environment for humans, for example, space exploration, where humans lack the physical capabilities of surviving the extreme external conditions, or monitoring a cloud of air filled with lethal pollutants. To that effect, various research has been conducted in exploring the use of agent-based systems for air pollution monitoring.

1.1 Air Pollution Monitoring

Air pollution monitoring or air quality monitoring is part of environmental monitoring performed to assess the risk of harmful effects on the natural environment caused by human activities [2]. The substances that cause major degradation in the quality of air are particulate matter, carbon monoxide, ozone, nitrogen dioxide and sulphur dioxide [3]. Measuring concentrations of these pollutants in the ambient air is undertaken by authorities such as the Environmental Protection Agency to assess the status of air quality. Curbing air pollution is a complex task and as indicated by [4], while air pollution monitoring directly has no effect on reducing the pollution, it does provide us with valuable information about the quantity and presence of pollutants which could help in taking measures to reduce the said pollution.

1.2 Agents and Multi-Agent Systems

An agent is any entity which performs some tasks on behalf of some other entity/entities often humans. Agents in computing domain refer to software programs that carry out activities to provide results, these agents are said to be intelligent if they are capable of taking independent actions in response to the environment on behalf of their owners without being directed or interfered with constantly [5]. These agents are also termed as autonomous agents. The most important properties that define an intelligent agent are its autonomy and flexibility. While, autonomy refers to the ability of the agent to take decisions on its own without external guidance and interference, the intelligence of an agent can be viewed to be divided into various levels based on the characteristic properties of flexibility that an agent encompasses. The flexibility refers to the agent's ability to behave reactively, proactively and/or socially. A reactive agent is the most basic form of an intelligent agent, which is capable of taking actions or reacting to the events occurring in its environment. A proactive agent exhibits goal-oriented behaviour, which not only reacts to events, but also identifies opportunities to achieve a defined goal. Finally, an agent with the ability to interact with other agents to reach a collective goal by means of cooperation, coordination and/or negotiation is deemed as a social agent [6].

An environment in combination with an agent function which takes actions to affect the environment can be viewed as an agent system, for example, a warehouse with a robot that performs inventory management is an agent system, where the warehouse with its walls and the components stored within those walls is an environment and the robot is a physical embodiment of an intelligent agent. However, in real-world a warehouse inventory management task cannot be handled by a single robot and may require multiple robots working in unison to get the job done, which is an example of a multi-agent system. Similarly, the nature of air pollution monitoring task is also that of a multi-agent system, where the pollutant levels need to be monitored in multiple places simultaneously. The defining property of a multi-agent system is the ability of a group of intelligent agents to work coherently towards maximizing an objective goal or the utility in the system.

1.3 Multi-Agent Systems for Air Pollution Monitoring

Multi-agent system is an interdisciplinary field and so is environmental monitoring. [7] suggests that the fields of data fusion (collection of data from multiple sources and integration in a global environment), cooperative perception in robotics and intelligent sensor networks

evolve into multi-agent approach to environmental perception for monitoring air pollution, electromagnetic pollution and meteorological monitoring. Different research studies have explored the area of air pollution monitoring as a multi-agent system, either by simulating the environment involved to optimise the measurement techniques by focusing on cooperation strategies among intelligent agents or going a step further to predict the evolution of pollution and simulating a system with an aim of reducing the emissions by using rewards and penalties.

2   Monitoring Approaches

2.1   Non-Agent Based Systems

Air pollution monitoring is performed by collecting samples and weighing and analysing these in labs. This process may be conducted manually or through automated systems [4]. Traditional or conventional air pollution monitoring involves use of pollutant sensors installed at fixed locations to collect concentration measurements. Vehicles equipped with monitoring instruments flexes the static nature of such systems by allowing mobility, however, these are also limited in their use. [8] suggests that such traditional methods do not provide accurate monitoring and [9] points out that these systems are quite expensive as well.

2.2   Multi-Agent Based Systems

The use of multi-agent system to model air pollution monitoring network and activities has been suggested in number of studies over the past two decades, and with the current advancements in sensor technology, sensor networks, data collection paradigms, and artificial intelligence the adoption of such a system could prove to be very beneficial.

Some of the initial work done by [8], simulated the application of small flying helicopter models as agent societies for monitoring a pollutant cloud generated around the chimney of a power plants, which are a major cause of emitting pollutants in the air. With the traditional approaches it is quite difficult to accurately monitor a pollutant cloud, given the hostile (inaccessible), dynamic and non-structured nature of the environment, but the implementation provided by [8] intended to provide an intelligent search method that worked better than individual screening. Individual agents or sensors may provide redundant and overlapping measurements, whereas [8] showed that multiple helicopter agents equipped with perception, actuation and computation devices for collecting pollutant samples and communicating with other agents through radio emitter could be programmed to learn how to collect the measurements efficiently in the large search space while collaborating with each other. [8] reported that a non-interference strategy presented in [10], worked much better compared to traditional setting and could be improved further by using follow group and gather group strategies for designing the behaviour of the agent societies.

A 2013 study presented in [11] implemented an agent system to monitor pollution around the entire power plant rather than at the power plant chimney increasing the search space of the environment significantly to an entire city where the power plant was located. Through simulation of four agents located around different regions of the city, [11] concluded that use of multi-agent system can prove useful in environmental decision making when air pollution episode occurs through collaborative intelligence.

Another multi-agent coordination approach involving crowdsensing to collect measurements through participatory sensing was discussed in [12]. Participatory sensing involves use of low-cost mobile devices equipped with sensors for pollution measurement by common people, enabling large scale data collection covering large area. However, this approach also faces the problem of overlapping measurements, thus [12] introduced a novel algorithm called Local Greedy Search based on entropy and mutual information for coordinating measurements among these collection devices (agents) taken at spatial and temporal coordinates representing the environment for maximizing the entropy-based utility.

The experiments performed by [13] showed that multi-agent system could be used not only to monitor the air pollution, but also to control the emissions by defining a cooperation strategy that rewards or penalises the action of agents (emission source controllers and air pollution controlling agency) based on whether they chose to increase or reduce the emissions.

The multi-agent systems for air pollution monitoring have considerably more benefits over traditional systems in reducing costs of equipment, covering large search space and avoiding exposure to the harmful pollutants.

3   Moving Towards Multi-Agent Air Pollution Monitoring Systems

Use of multi-agent systems for air pollution monitoring has the potential to provide huge positive impact in dealing with air pollution which is responsible for seven million premature deaths as reported by World Health Organization [1]. Current approaches impose heavy restrictions on collection and access of the monitored data which limits the capability of both public and private authorities to implement policies to reduce air pollution [9], however, with the paradigms discussed in the previous sections these limitations could be dealt with. Multi-agent systems are based on the principles of non-interference, and by delegating the task of efficient collection of pollutant measurements, the focus of experts could be shifted more towards reducing pollution rather

than monitoring it. [1] also states that the "International efforts to deal with air pollution began in 1972 and continue with limited success", and multi-agent systems may help speed up the process by application of learned strategies. An emission monitoring project by WattTime backed by Google is in works, which aims to use satellite imagery to monitor real-time air pollution emissions from each and every power plant in the world [14, 15] and make the data public. Future systems could be designed to use this data to reduce emissions with a framework like the one implemented by [13].

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