Ship Exhaust Real-Time Monitoring System based on Automatic Identification System

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ABSTRACT
Maritime traffic is a major source of pollutant gases and we believe that it is important to quantify these gases in order to assess their impact on the environment. This paper proposes a maritime monitoring system able to estimate in real time the emissions of carbon dioxide (CO_2) and particulate matter (PM) from ships crossing the Strait of Gibraltar area. The system works based on the Automatic Identification System (AIS) : it consists of an AIS receiver connected to a computer in which was installed an application able to determine, store and display emissions from ships. The computer application was performed according to a method for estimating CO_2 and PM emissions from AIS data. The system was installed near the Strait of Gibraltar (exactly in Tangier - Morocco) and tests were carried out for about a month (between March 26 and April 23, 2014). The system recorded emissions from 900 to 4000 tons of CO_2 and 2 to 9 tons of PM each day.

Keywords
Real-time system, ship emissions, maritime traffic, strait of Gibraltar

1. INTRODUCTION
Exhaust emissions from ships can be transported in the atmosphere over hundreds of kilometers and contribute to air quality problems inland [1], [2]. Automatic Identification System (AIS) is basically used by ships and Vessel Traffic Service (VTS) for monitoring maritime traffic, however, several studies were conducted to propose methods to calculate the amount of pollutant gases emitted by ships using AIS data [3] - [5]; but most of these methods use historical data (journeys carried by ships) and are not capable of providing real-time data.

The Strait of Gibraltar is a busy waterway, but at present, few studies have been conducted to know the level of pollutants gases emitted by ships crossing through this region. This paper proposes a system, operating in real time, able to estimate the amount of pollutant gases emitted by ships crossing the Strait of Gibraltar (the west of the Strait of Gibraltar and part of the northern Moroccan Atlantic coast). The system is based on a method for estimating carbon dioxide (CO_2) and particulate matter (PM) emissions using AIS data [6]. CO_2 and PM are known respectively to be harmful to the environment (greenhouse gas) and human health (carcinogenic gas) [7], [8].

2. MATERIALS AND METHODS
2.1. AIS receiver
The Automatic Identification System (AIS) allows ships to broadcast regularly data within a range of about 70 km using radio waves (Very High Frequency - VHF). The AIS consist of an AIS transmitter which broadcasts data and an AIS receiver which receives data. The data sent by the AIS transmitter is : vessel type, length, width, draft, speed, geographical position, direction, destination, etc.

An AIS receiver was installed near the Strait of Gibraltar, exactly at the Faculty of Sciences and Technology of Tangier in Morocco (35° 44' 9.96" N, 5° 53' 42.292" W). The AIS receiver is connected to a VHF antenna and covers the western of the Strait of Gibraltar and a part of the northern Atlantic coast of Morocco (figure 1). The received data is stored in a database and displayed in a Graphical User Interface - GUI (figure 1).

Fig 1: Screenshot of the system GUI showing ships crossing the Strait of Gibraltar on April 11, 2014 at 3:32 pm

2.2. The method
To estimate CO_2 and PM emissions from ships, the method uses the following steps : AIS data (vessel type, length, width, draft, geographical position and navigation speed) is collected for each ship, and then, ship resistance, propulsion power, engine power output and fuel consumption are calculated using mathematical formulas; in the last step, CO_2 and PM

emissions are determined depending on fuel consumption and type. Figure 2 summarizes the steps of the method. More detail about this method is presented in [6].

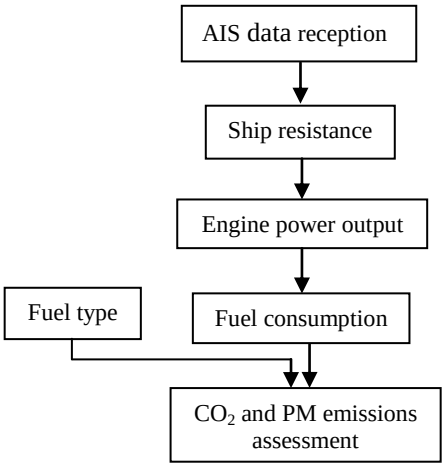

Fig 2: Stages of the method

This method is valid for cargo ships, tanker ships and passenger ships. The CO_2 and PM emissions are those from the main engine, emissions from auxiliary engines and boilers are not taken into account.

2.3. The CO_2 and PM emissions estimator application

The data captured by the AIS receiver is stored in a database (AIS Database) and then used by the computer application. The application estimates the CO_2 and PM emissions on each ship, stores this data in a database (Emissions Database) and then displays it on a GUI (graphical user interface). Figure 3 shows the system operation scheme.

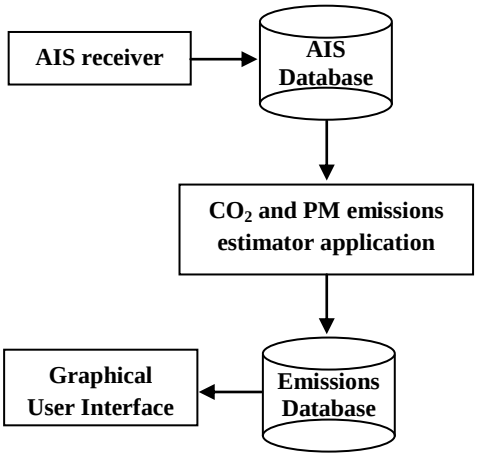

Fig 3: The system diagram

The AIS Database stores for each ship, data such as ship type, length, width, draft and speed, direction, location, etc. This data is used by the computer application as basic parameters for estimating the amount of CO_2 and PM emitted by ships. The Emissions Database stores ship emissions data (the amount of CO_2 and PM emitted every minute by a ship).

3. RESULTS

The system was installed near the Strait of Gibraltar and tested for 28 days (between March 26 and April 23, 2014). The data collected by the system gives information about maritime traffic and the amount of CO_2 and PM generated by ships spotted in this area (blue area shown in figure 4).

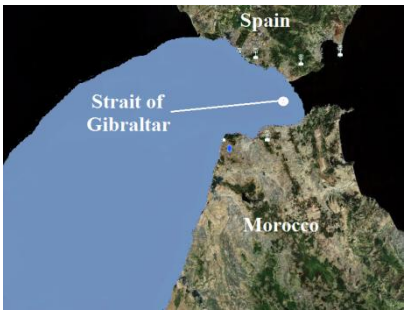

Fig 4: The area covered by the system (blue area)

3.1 Maritime traffic

During the trial period, the system recorded 4499 crossings of ships in which 2800 (62.24%) are cargo ships, 1034 (22.98%) tanker ships, 151 (3.36%) passenger ships, 72 (1.6%) other types of ship (military, pleasure craft and fishing) and 442 (9.82%) unidentified ships (table 1). An unidentified ship is a ship transmitting AIS data without giving information about its type or size.

Table 1. Observed ship traffic by the system between March 26 and April 23, 2014

Ship type	Number of crossings	Percentage
Cargo	2800	62.24%
Tanker	1034	22.98%
Passenger	151	3.36%
Other type	72	1.6%
unidentified	442	9.82%
Total	**4499**	**100%**

It is considered a crossing, when a ship is spotted in the system coverage area (blue area shown in figure 4) within a day. Figure 5 shows the daily traffic observed during the trial period.

3.2 CO_2 and PM emissions

The CO_2 and PM emissions data is given in real-time (data is refreshed every minute and given in kilograms per minute). Figures 6 and 7 show respectively the daily emissions (in tons per day) of CO_2 and PM from cargo ships, tankers and passenger ships: the emissions are about 900 tons of CO_2 and 2 tons of PM when traffic is relatively low (about 100 crossings per day) and about 4000 tons of CO_2 and 9 tons of PM when traffic is high (over 200 crossings per day). Cargo ships, tankers and passenger ships contribute, respectively, about 73%, 23% and 4% of the emissions.

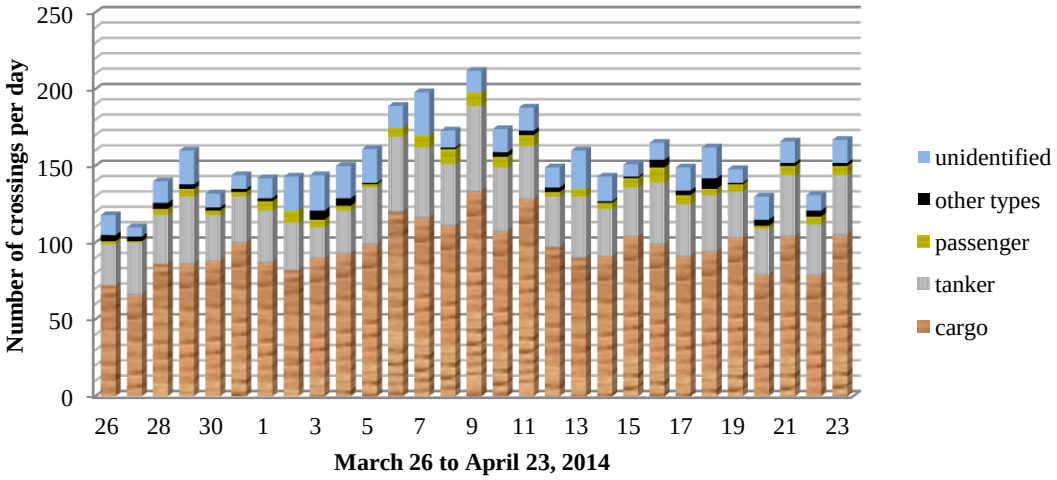

Fig 5: Observed daily traffic between March 26th and April 23rd, 2014

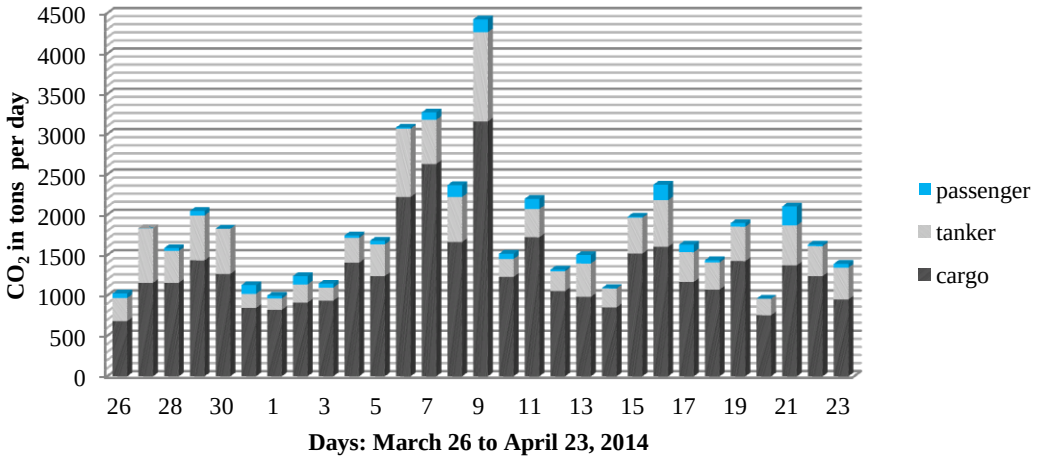

Fig 6: Estimated CO_2 emissions between March 26th and April 23rd, 2014

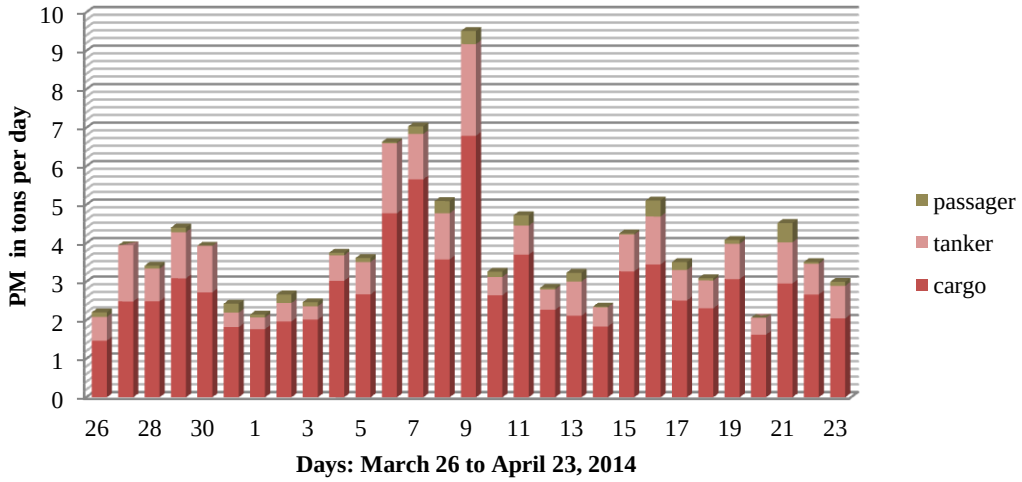

Fig 7: Estimated PM emissions between March 26th and April 23rd, 2014

4. DISCUSSION

The traffic observed during the trial period is dominated by cargo ships, tanker ships and passenger ships, they represent more than 88% of the all traffic, but it is important to note that this system only spots ships fitted with an AIS transmitter. AIS is a mandatory system in all ships engaged on international voyages and whose gross tonnage exceeds 300 tons [9]; however, some small ships, including fishing and pleasure craft are not fitted with AIS, so they cannot be detected by the system.

Figure 5 shows that traffic is high on certain days such as 9th April 2014 (over 200 crossings). High maritime traffic on the system is probably due to the radio wave propagation conditions through the troposphere (tropospheric ducting). Indeed, the range of the radio waves can be influenced by tropospheric ducting [10]: in theory, the range of the AIS signals (VHF waves) is about 70 km, but when tropospheric ducting happen, the range of the AIS signals increases and the system is able to spot ships at more than 200 km. So this phenomenon can increase greatly the number of ships detected by the system. However, it was found that when weather conditions are bad (strong wind, rough seas), such as 26th March and 20th April 2014, traffic is relatively low (about 120 crossings).

The CO_2 and PM emissions are generally proportional to the maritime traffic intensity. However, CO_2 and PM emissions presented in figures 6 and 7 do not necessarily follow the maritime traffic data shown in figure 5. This is due, firstly, to the fact that the data presented in figures 6 and 7 is the emissions from cargo ships, tankers and passenger ships only (the other ship types are not taken into account) and secondly, to the size of ships. Indeed, if one takes two days such as 21th and 23th April 2014, the number of crossings are similar (figure 5), but the CO_2 and PM emissions (figures 6 and 7) are significantly different (emissions are higher on 21th April). This can be explained by the size of the ships detected in these two days: from 166 ships detected on 21th April, 35 ships have more than 100 meters length and from 167 ships detected on 23th April only 20 ships have more than 100 meters length. So that leads us to believe that more the number of large ships is high, more the CO_2 and PM emissions are high.

5. CONCLUSION

AIS was designed to monitor ship traffic but also to help ships reduce the risk of collision. The purpose of this study is, firstly, to show that the AIS data can also be used to quantify in real time the pollutant gases emitted by ships, and secondly, to assess the level of CO_2 and PM emitted by ships crossing the Strait of Gibraltar area (the west of the Strait of Gibraltar and a part of the Moroccan Atlantic coast north). To achieve these goals, a monitoring maritime system based on AIS was developed.

The data provided by this system can be used to monitor emissions from ships crossing the Strait of Gibraltar and also to assess the impact of maritime traffic on air quality in this region [11].

So far, the method developed and used in this study only takes into account emissions from the main engines. We plan to improve this method to also be able to estimate emissions from auxiliary engines and boilers.

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