THE POTENTIAL OF THE REMOTE SENSING METHOD FOR VEHICLE INSPECTION PROGRAMS

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ABSTRACT
Results are presented of an assessment of the potential of the remote sensing technology to supplement current inspection procedures regarding emissions from motor vehicles and to improve the process of identifying big polluters.
About 20,000 vehicles were tested for CO, HC, CO_2 and NO_x emissions, using the remote sensing system manufactured by the MD Lasertech Co. More than 200 vehicles were tested also at idle in accordance with the current European inspection procedure. Methods of dirty and clean screening were checked and errors of commission as well as errors of omission were evaluated for various CO cut-points. Improvement of the inspection results was estimated, when compared with the data of two series of random roadside tests without remote sensing, which were carried out in 1997 and 2001.
Key words: vehicle emissions, enforcement, CO cut-points, air pollution.

INTRODUCTION
Efforts to reduce air pollution by motor vehicles are approached in two main directions, treating either new or in-use vehicles. For the former, a substantial success has been achieved: as mentioned in [2], new production vehicles emit now less than 4% of carbon monoxide (CO) and hydrocarbons (HC) compared to their pre-control counterparts (reduction of 96%). Unfortunately, the situation is deteriorated as soon as the vehicle starts its in-use life cycle – slowly at the beginning and faster later, when the catalytic converter becomes aged and in particular when the maintenance level is inappropriate. Common evidence clearly indicates that in-use vehicles are the reason that air quality goals have not yet been met [2,3,5].
It is well established now that a relatively small part of the vehicle parc, having excessive emissions and called big polluters, is responsible for a very high proportion of total emissions. Figure 1, presenting results of a test, which was carried out in Israel [4], shows that about 10% of the gasoline vehicles fleet are responsible for about a half of the total vehicle emissions [4]. These results are well correlated with those obtained by others [5,6] and clearly indicate that identifying these big polluters and repairing them could lead to significant improvement of the air quality.
Current European inspection & maintenance (I/M) programs [7] are based on periodical (usually annual) and random roadside tests of CO concentrations in vehicle exhaust at idle and fast idle regimes. These measurements are usually carried out by conventional NDIR gas analyzers, require driver cooperation and, therefore, are time and labor consuming.
The objectives of this work were to assess the potential of the remote sensing technology to supplement current inspection procedures and to improve the process of identifying high polluting vehicles together with reducing the number of compulsory idle tests.
It is noted that our remote sensing research program is much more extensive, consisting of further goals and including experiments, which are not subject of this paper and will be described in another paper.

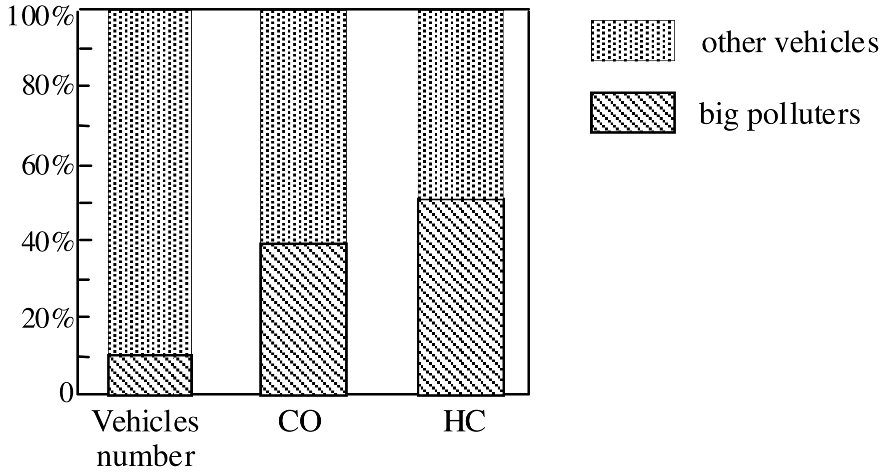

Figure 1. Contribution of big polluters to the total vehicle emissions in Israel [4]

DESCRIPTION OF THE REMOTE SENSING TECHNOLOGY

The remote sensing equipment for measuring concentrations of CO, HC, CO_2 and NO_x is based on the attenuation of electro-magnetic beams, which are radiated from two sources (IR, UV), traverse through the exhaust gas plume and detected by a sensor. A schematic arrangement of the system for measuring emissions from vehicles (while driving) appears in Figure 2 (adapted from [6]).

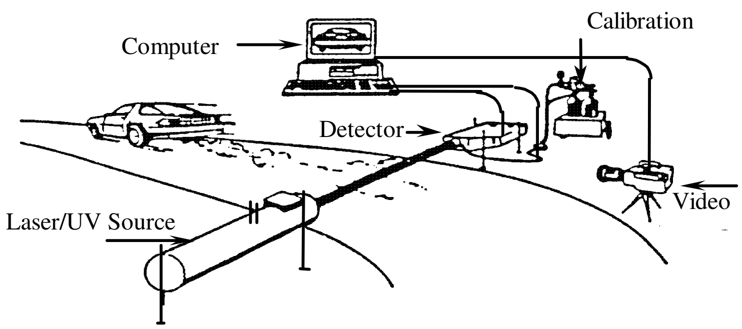

Figure 2. Layout of remote sensing system for measurement of vehicle emissions

In the present work, use was made of remote sensing equipment manufactured by MD Lasertech. The system is based on technology initially developed by Prof. D. Stedman from the University of Denver.

When a car passes through the system, it first blocks the ray, which starts the measuring procedure by commanding the equipment to get ready. During the passage of the rays in the plume, the gas molecules and the particulates absorb and disperse parts of the radiation. Thus the energy reaching the sensor is lower than that leaving the source. The attenuation of the intensity depends on the pollutants concentrations, and the system computer performs the calculations and displays them on the monitor (see example in Figure 3). A video camera, which is located near the radiation source records the license plate of the vehicle, in order to obtain, later, its specification. The system measures the car speed and acceleration, as well as wind speed and direction, which also appear on the monitor. According to the manufacturer of the system, the measurement of molar ratios of the pollutants to that of the CO_2 is more accurate, since it compensates for errors resulting from such effects as location of the exhaust gas plume with respect to the beam, wind, total emission rate from the vehicle engine, etc. However, the absolute values of pollutants concentrations are obtained by assuming a stoichometric equation of combustion, which is not always the case. This equipment can be used only for gasoline vehicles, where CO and CO_2 concentrations are measured by absorption of IR radiation and those of NO and Butadiene of UV radiation. The system cannot account for scattering by particulates from diesel engines. The measurement is also based on initial calibration against a reference gas mixture, which contains CO_2, CO, HC and NO.

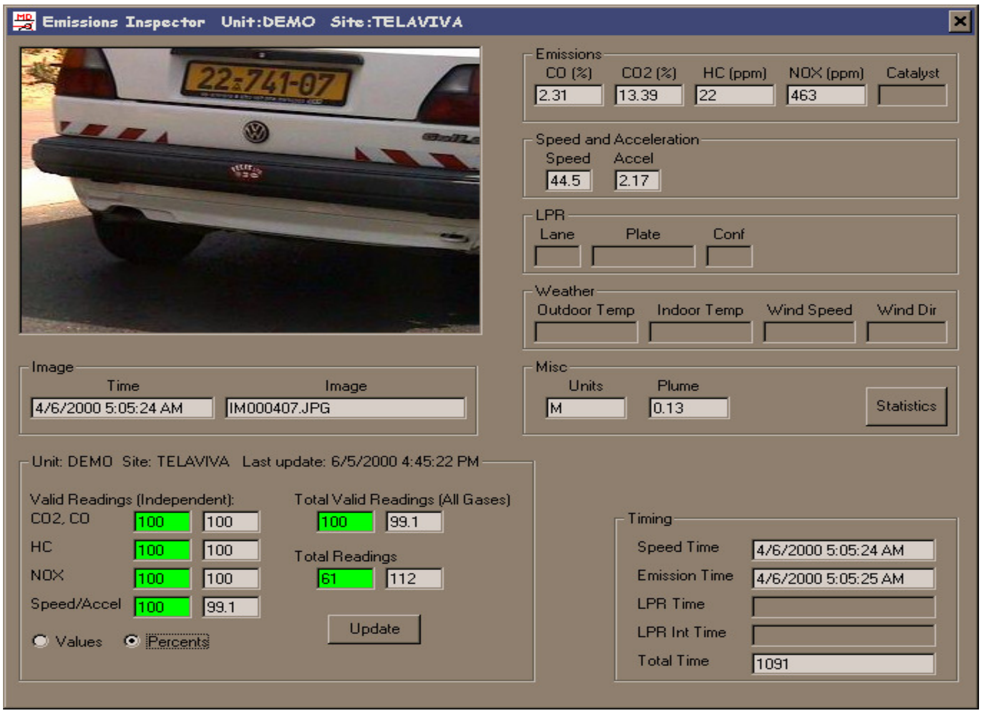

Figure 3. Output of the computer display after measurement (Israel, April 2000)

METHODOLOGY

Remote sensing (RS) measurements: The RS system was set up according to the recommendations of the manufacturer. Usually, one lane road with a slight positive gradient was chosen as a measurement site. Two additional special requirements were taken into account during site choosing:

- possibility "to mask" the RS system on the road side, in order to prevent inquisitive drivers from slowing down or stopping their vehicles;
- presence of enough space downstream of the RS system, which may be suitable for placing a conventional roadside emissions test site.

The following parameters were measured/monitored and saved in the computer memory by the RS system for each passing vehicle: concentrations of CO, CO_2, HC and NO_x; vehicle speed and acceleration; wind speed and direction; ambient temperature and license plate.

Roadside emission measurements: These tests were carried out according to the requirements of [7] using conventional 4 gases NDIR gas analyzer. Concentrations of CO, CO_2, HC and O_2 in the exhaust gases and lambda values were measured for each vehicle that was stopped by a policeman for the test. Additionally, all relevant vehicle and trip data, such as: make, model, production year, engine volume, date of last annual test, traveled distance, estimated driving time, etc. were registered in cooperation with the vehicle driver. These conventional emission tests were carried out for random vehicles that were stopped and tested, and for "targeted" vehicles based on upstream RS measurements.

The work, which is reported in this paper, included three basic series of experiments:

- Special series of tests, aimed at comparison of RS and conventional measurements;
- Dirty screening experiments;
- Clean screening experiments.

Obviously, for comparison between the RS and conventional methods, only CO values can be used. Therefore, only these values are presented here and all other results will be dealt in another paper.

Comparison tests included experiments with direct comparison of simultaneously performed RS and conventional measurements on a same vehicle, with the same engine operation regime. Comparisons were also performed between the results of RS measurement of driving a vehicle and conventional measurement of the same vehicle at idle.

Dirty screening experiments were aimed at development of a method, based on cut-points, which would enable to supplement the current European I/M procedure in identifying high polluting vehicles. Only CO cut-points of RS measurements were investigated in this work, in the range 4% to 10% concentrations. Errors of commission (inclusion) were evaluated in the same way, as that of the comprehensive European project completed by TRL in 1998 in cooperation with some other leading research organizations [1].

Clean screening experiments were aimed at development of the method and cut-points, which will enable to supplement the current European I/M procedure in allowing clean vehicles to be spared from the labor and time consuming conventional idle test. CO cut-points of RS measurements were investigated ranging from 0.2% to 6% concentrations. Errors of omission (exclusion) were evaluated.

RESULTS AND DISCUSSION

The experiments were performed during two and a half months. The measurements were carried out in many sites in Haifa and also in Jerusalem. About 20,000 vehicles were tested using the remote sensing system, and emissions of 215 vehicles were measured by the RS system and at idle by a conventional NDIR gas analyzer.

Figures 4 presents results of a comparison between CO measurements by RS of driving vehicles, and by conventional gas analyzer of the same vehicles at idle. Almost no correlation was found, because in this case the compared results were observed at quite different engine operation regimes – loaded driving and idling. This is in good agreement with the findings of [1].

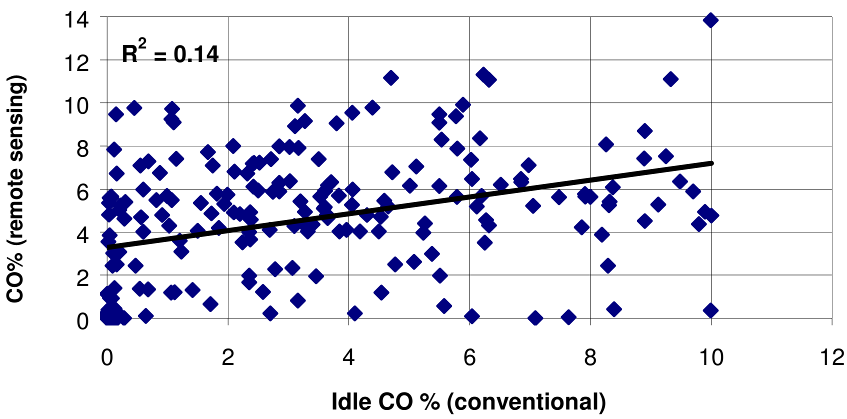

Figure 4. Correlation between conventional and RS measurements of CO emissions

As mentioned above, special series of experiments were carried out in order to compare directly RS and conventional NDIR CO measurements at a same engine operation regime. Two passenger cars, with and without catalytic converter, were simultaneously measured at idle. In order to prevent possible errors of RS measurement due to a static vehicle condition, the cars were rolled-on downhill at neutral gear position. Conventional measurement was performed on-board the vehicles and the RS system worked in its usual manner. The results are shown in Figure 5.

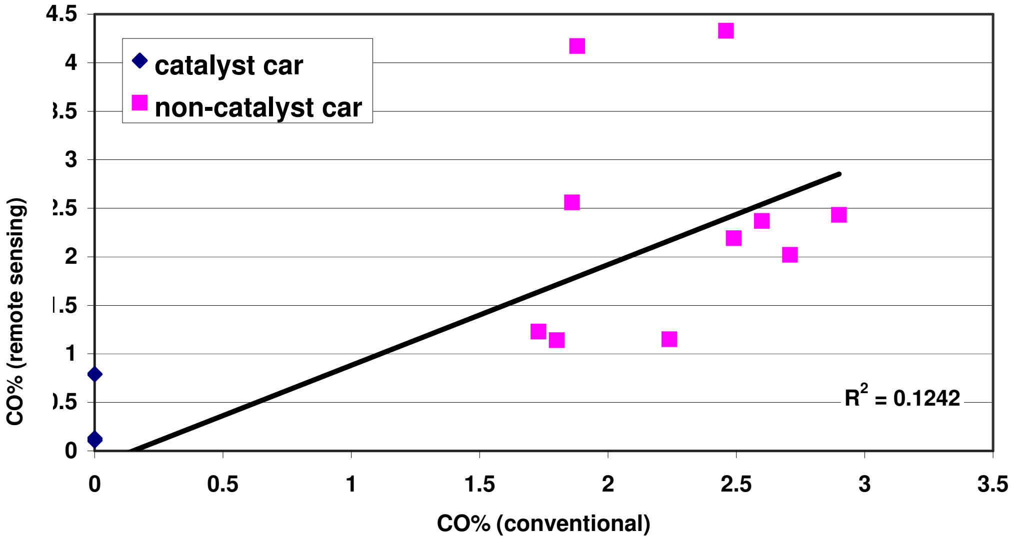

Figure 5. Comparison between simultaneous RS and conventional measurements

As can be seen from the Figure 5, the correlation is quite weak (R^2 = 0.12). Similar results were obtained in [2] and were attributed mainly to the vehicle emissions variability, and not to the testing procedure. It was also noted in [2] that emissions variability increases with increasing average emissions, and it appears to be prevalent among big polluters.

Table 1 shows the results of a statistical processing the CO measurements that are presented in Figure 5.

Table 1. Results of statistical processing the conventional and RS CO measurements

Vehicle type	**Conventional measurement, %**				**RS measurement, %**			
	Max	Min	Average	**StDev**	Max	Min	Average	**StDev**
Non-catalyst car	2.9	1.65	2.21	**0.44**	4.33	0	2.14	**1.30**
Catalyst car	0	0	0	**0**	0.79	0.11	0.34	**0.39**

As can be seen from Table 1, the results of this work confirm the statement of [2] concerning the increase of emissions variability with increasing average emissions. At the same time, we are in doubt regarding the conclusion that only the vehicle, and not the testing method, is the main reason of observed emissions variability, in particular concerning the remote sensing method. It may be seen clearly from Table 1 that the values of the standard deviation of the conventional measurements are much less than those of the remote sensing.

Nonetheless, these results confirm the conclusion of [2] regarding the need of multiple vehicle tests, and in this case RS technology may be very useful, because of its high productivity. On the other hand, it seems that at the current status of its technological development, the RS systems may be used only as a supplement tool for the conventional I/M procedures.

Taking into account the results and conclusions mentioned above, possibilities were checked of using the RS method for dirty screening and for clean screening. The results that were obtained are shown in Tables 2 and 3, where the errors of commission and of omission were calculated according to [1], as a percentage of vehicles:

- identified by RS as big polluters, but passed the conventional idle test – error of commission;
- identified by RS as clean vehicles, but failed in the conventional idle test – error of omission.

The rate of success was calculated as the percentage of vehicles successfully identified as big polluters (Table 2) or as clean vehicles (Table 3).

Table 2. Results of using RS as a dirty screening tool (CO_{RSD} is the value of CO concentration measured by the RS system)

CO_{RSD}, %	Total No. of measured vehicles	No. of vehicles failed in the idle test	Rate of success, %	Error of commission, %
4+	139	67	48	52
5+	103	53	51.5	48.5
6+	63	34	54	46
7+	45	24	53	47
8+	25	17	68	32
9+	19	13	68.5	31.5
10+	5	5	100	0

Table 3. Results of using RS as a clean screening tool

CO_{RSD}, %	Total No. of measured vehicles	No. of vehicles passed the idle test	Rate of success, %	Error of omission, %
≤0.2	28	25	89	11
≤0.5	36	31	86	14
≤1	39	34	87	13
≤2	52	44	85	15
≤3	61	48	79	21
≤4	69	53	77	23
≤5	76	58	76	24
≤6	83	61	73	27
Measurements at idle without RS	*98*	*67*	*68*	
Measurements at idle without RS in 1997	*350*	*235*	*67*	

As can be seen from Table 2, establishing the CO cut-point for dirty screening at 8% or more, as measured by the remote sensing system, enables identification of big polluters with about 70% rate of success. It is important to note that without remote sensing, only one third of the tested vehicles usually fail in the conventional European idle test (see Table 3). Therefore, the improvement is more than twice. From the measured sample of about 20,000 vehicles, 2% were found with CO emissions of 8% or more. At the same time, it has to be noted that the errors of commission obtained are much bigger compared to those reported in [1]. For example, for RS CO cut-point of 5%, which was suggested in [1], the error of commission obtained is above 48% (see Table 2) compared to only 12% in [1].

Using remote sensing as a clean screening tool enables to reach a rate of success of about 90% and an error of omission of only 11%, if the CO cut-point is determined as 0.2% or less (see Table 3). These clean vehicles represent about 35% of the total measured vehicle fleet. It is important to note that errors of omission obtained in this work are similar to those reported in [1]. For example, for RS CO cut-point of 5%, the errors of omission were 25% in [1] and 24% in the present work. As anticipated, it is clearly illustrated by the values in Table 3 that with increasing the RS CO cut-point the rates of success in identifying clean vehicles approach the values obtained in random tests without remote sensing.

CONCLUSIONS

About 20,000 vehicles were tested for emissions by using the remote sensing technology, 215 vehicles were measured by both the RS system and at idle by a conventional NDIR gas analyzer.

Almost no correlation was found between RS measurements of CO concentrations of driving vehicles and conventional measurement of the same vehicles at idle, because in this case the compared results were observed at quite different engine operation regimes – loaded driving and idling.

The results of the present work confirm the published statements concerning the increase of emissions variability with increasing vehicle average emissions. At the same time, we are in doubt regarding the conclusion that only the vehicle, and not the testing method, is the main reason of the measured emissions variability, especially, as concerns the remote sensing method. The results obtained in this work confirm the earlier findings regarding the need of multiple vehicle tests, and here the RS technology may be very useful, because of its high productivity. On the other hand, it is concluded that at the current status of its technological development, the RS systems may be used only as a supplement tool to the conventional I/M procedures.

Establishing the CO cut-point of 8% or more for dirty screening, as measured by the RS system, enables identification of big polluters with about 70% rate of success. Without remote sensing, only one third of the tested vehicles usually fail in the conventional European idle test. Therefore, the improvement is more than twice.

Using remote sensing as a clean screening tool enables to reach a rate of success of about 90% and an error of omission of only 11%, if a CO cut-point of 0.2% or less is used.

Finally, it is foreseen that much simpler RS equipment, for measurement of only CO concentration, may be enough for the dirty- or clean-screening purposes. Such a system would be less expensive, especially if operated in an unmanned mode, and would be appropriate for enforcement purposes.

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