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(54) **UNMANNED INTEGRATED OPTICAL REMOTE EMISSIONS SENSOR (RES) FOR MOTOR VEHICLES**

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(21) Appl. No.: **12/489,349**

(22) Filed: **Jun. 22, 2009** (Under 37 CFR 1.47)

Related U.S. Patent Documents

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Issued: **Mar. 10, 1998**
Appl. No.: **08/739,487**
Filed: **Oct. 26, 1996**

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G01N 21/00 (2006.01)
G01N 21/35 (2006.01)
G01N 21/25 (2006.01)

(52) **U.S. Cl.**
USPC **250/338.5**; 250/339.13; 250/252.1; 356/436

(58) **Field of Classification Search** 250/338.5, 250/339.13
See application file for complete search history.

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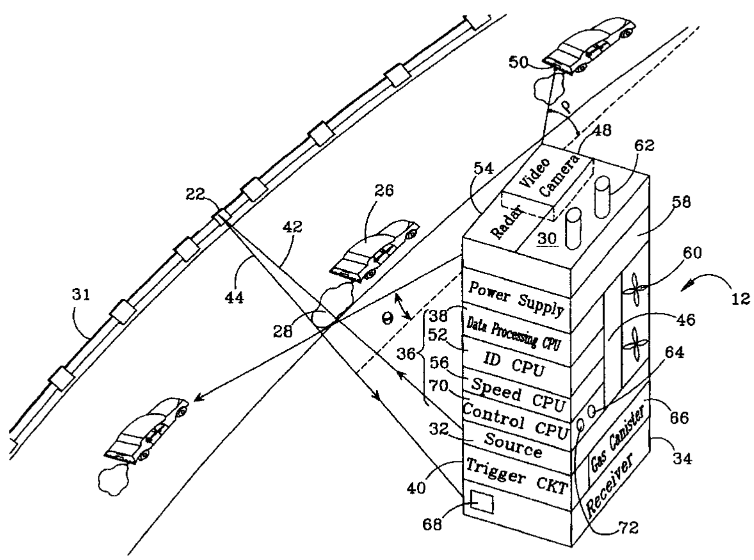
Primary Examiner — Marcus Taningco
(74) *Attorney, Agent, or Firm* — Pillsbury Winthrop Shaw Pittman LLP

(57) **ABSTRACT**

An unmanned integrated RES **12** integrates all of its components except the reflector **22** into a single console **30** that is positioned at the side of a road and has a CPU **36** that controls calibration, verification and data gathering. The RES's source **32** and receiver **34** are preferably stacked one on top of the other such that the IR beam **24** traverses a low and high path as it crosses the road **14**. This allows the RES to detect both low and high ground clearance vehicles. To maintain the vehicle processing and identification throughput, the speed sensor **54** and ALPR **48**,**50** detect the passing vehicles at steep angles, approximately 20 to 35 degrees. In a preferred system, a manned control center **16** communicates with a large number of the unmanned integrated RES to download emissions data, perform remote diagnostics, and, if necessary, dispatch a technician to perform maintenance on a particular RES.

7 Claims, 7 Drawing Sheets



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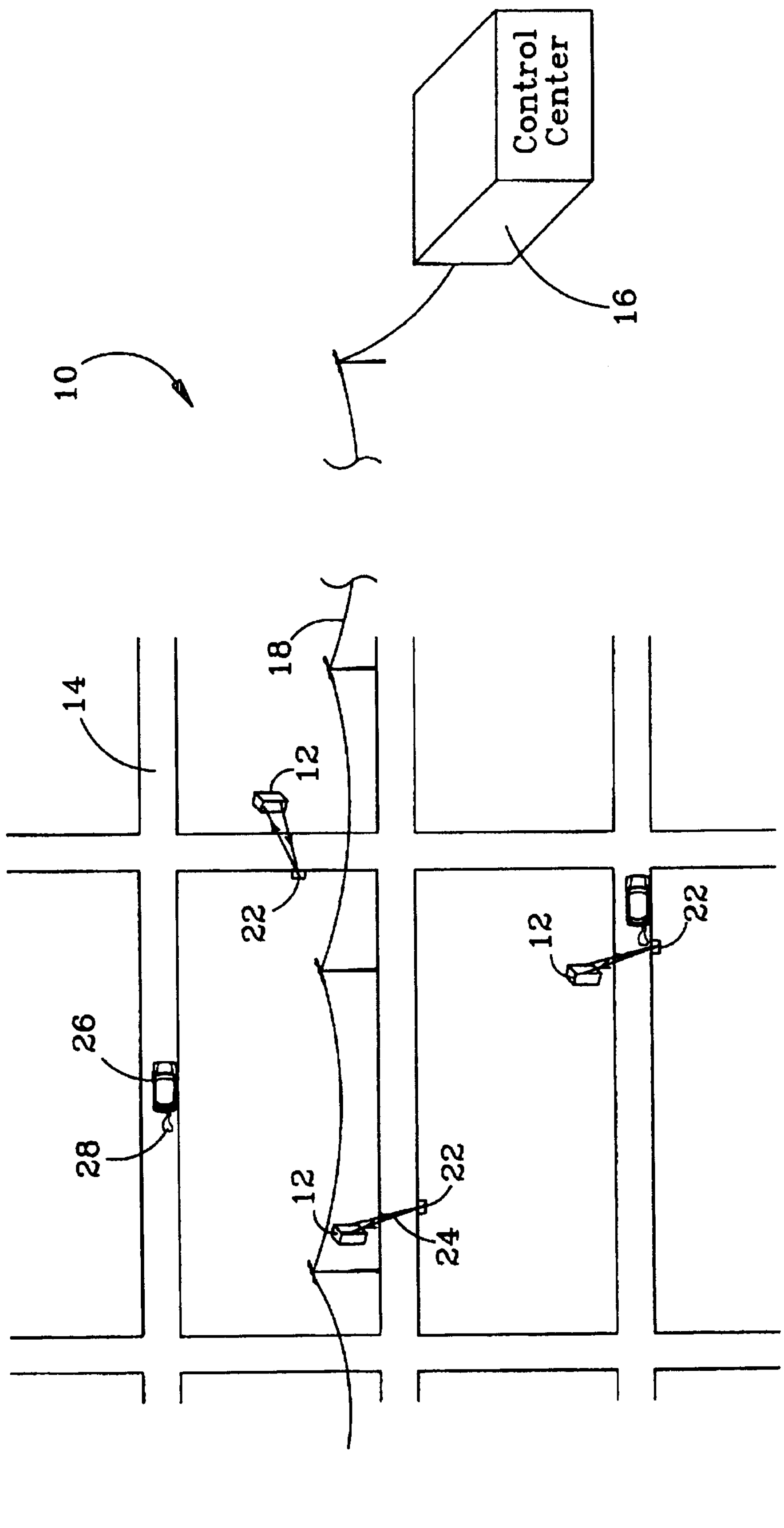


FIG. 1

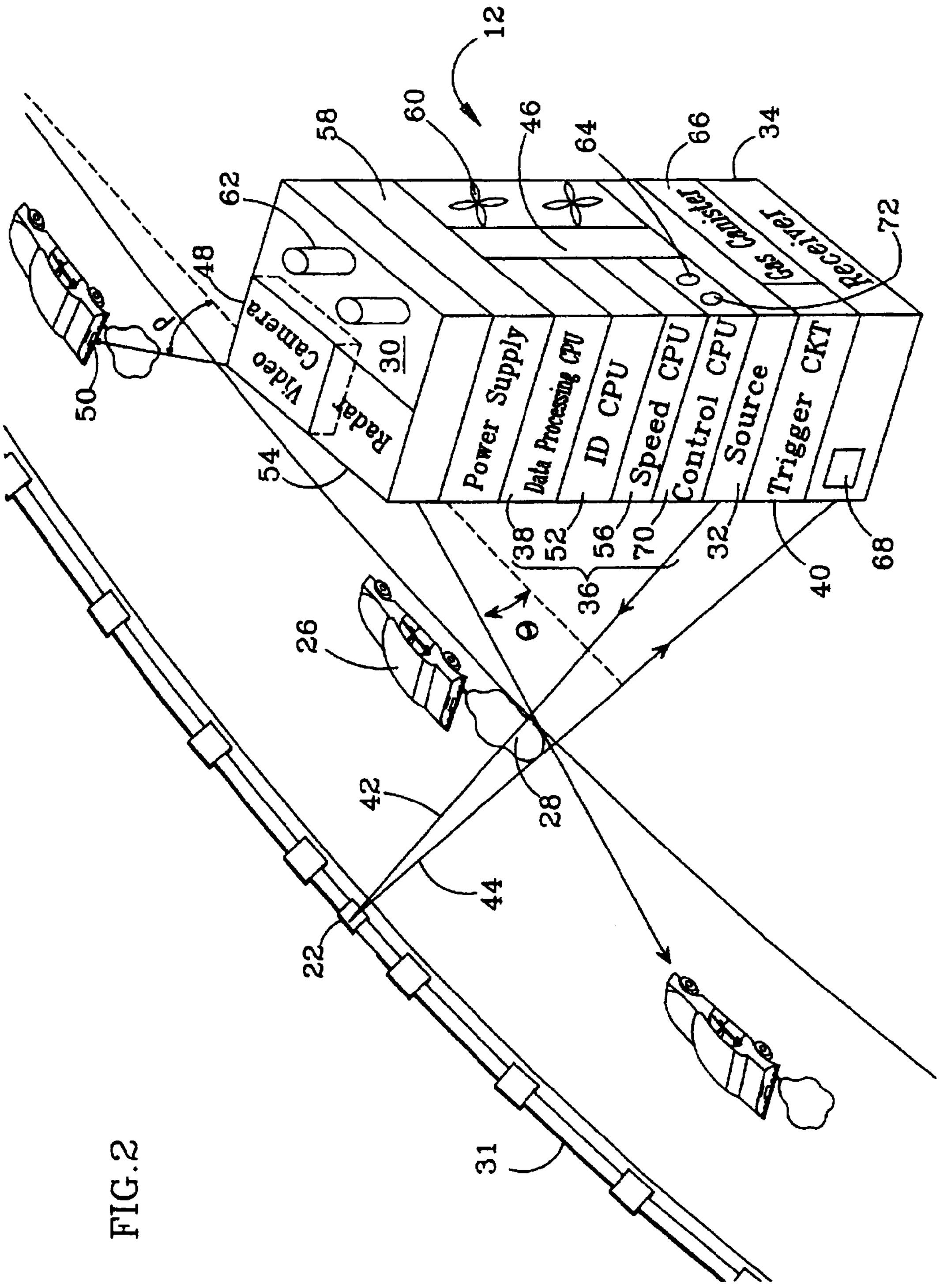

12
58
60
46
64
66
34
62
72
48
50
Video Camera
30
Radar
54
Power Supply
Data Processing CPU
ID CPU
Speed CPU
Control CPU
Source
Trigger CKT
Gas Canister
Receiver
38
52
56
70
32
36
40
68
26
28
42
44
22
31

FIG.2

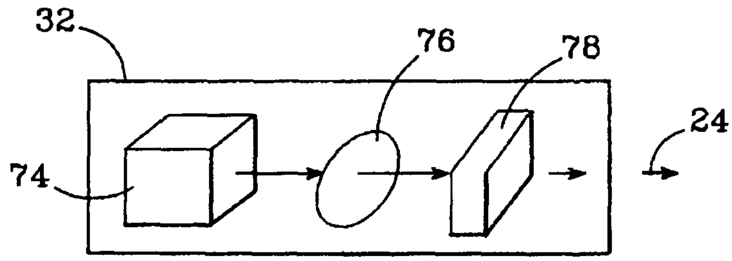
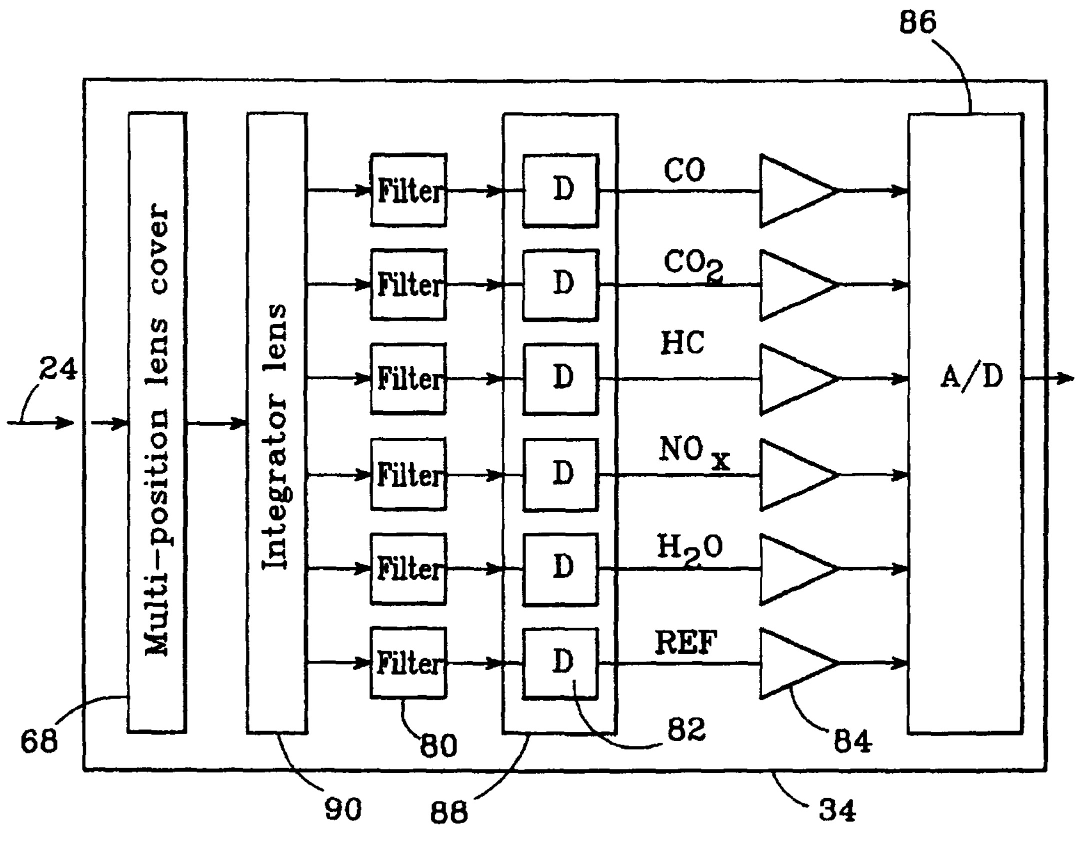

32
76
78
24
74

FIG.3


86
Multi-position lens cover
Integrator lens
Filter
Filter
Filter
Filter
Filter
Filter
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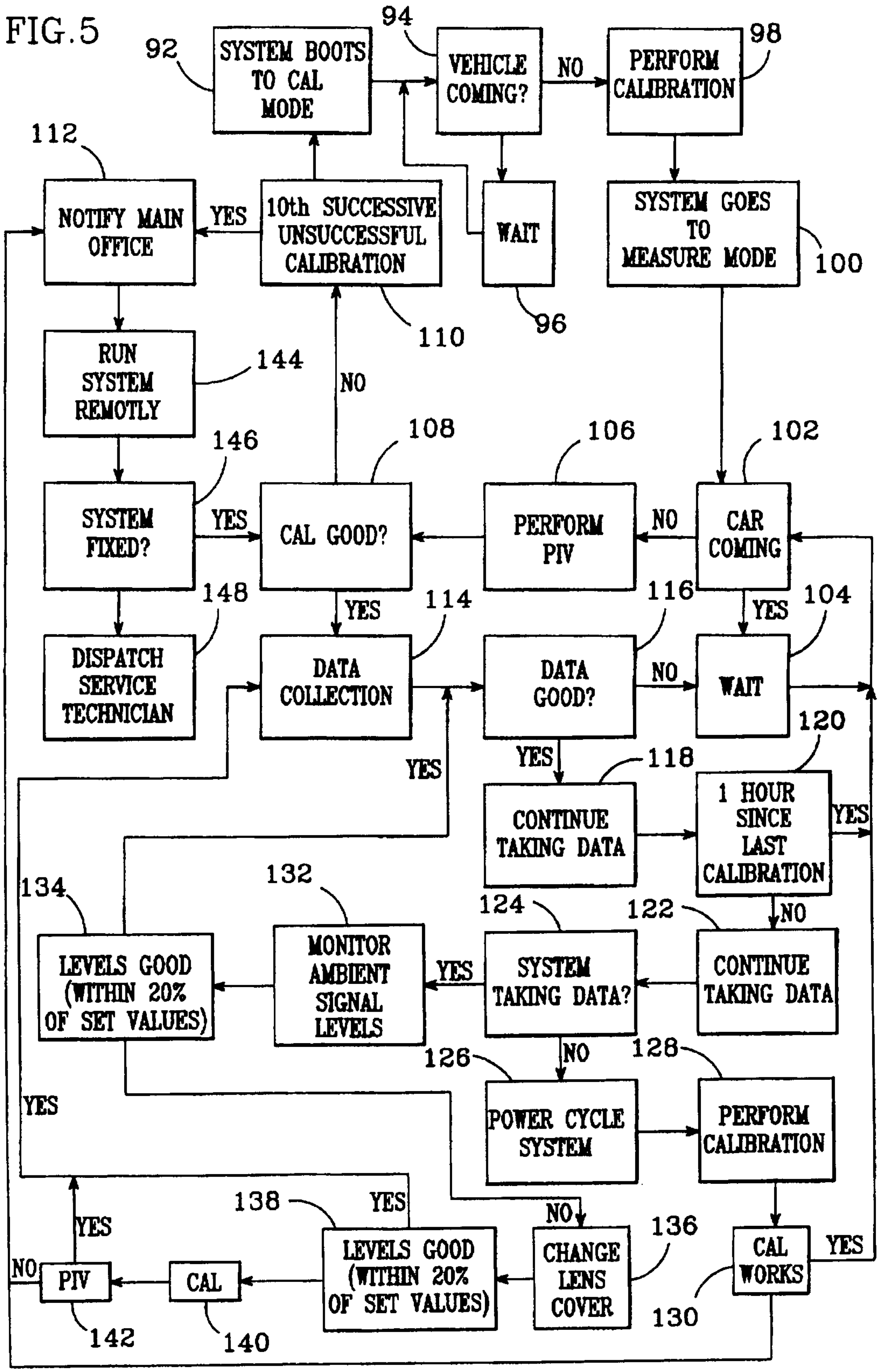
D
D
D
D
D
CO
CO_2
HC
NO_x
H_2O
REF
A/D
24
68
90
80
88
82
84
34

FIG.4

FIG.5



SYSTEM BOOTS TO CAL MODE
92
94
VEHICLE COMING?
NO
PERFORM CALIBRATION
98
112
NOTIFY MAIN OFFICE
YES
10th SUCCESSIVE UNSUCCESSFUL CALIBRATION
WAIT
SYSTEM GOES TO MEASURE MODE
100
96
110
RUN SYSTEM REMOTLY
144
NO
146
108
106
102
SYSTEM FIXED?
YES
CAL GOOD?
PERFORM PIV
NO
CAR COMING
148
YES
114
116
YES
104
DISPATCH SERVICE TECHNICIAN
DATA COLLECTION
DATA GOOD?
NO
WAIT
120
YES
YES
118
CONTINUE TAKING DATA
1 HOUR SINCE LAST CALIBRATION
YES
134
132
124
122
NO
LEVELS GOOD (WITHIN 20% OF SET VALUES)
MONITOR AMBIENT SIGNAL LEVELS
YES
SYSTEM TAKING DATA?
CONTINUE TAKING DATA
126
NO
128
YES
POWER CYCLE SYSTEM
PERFORM CALIBRATION
138
YES
NO
136
YES
YES
NO
PIV
CAL
LEVELS GOOD (WITHIN 20% OF SET VALUES)
CHANGE LENS COVER
CAL WORKS
142
140
130

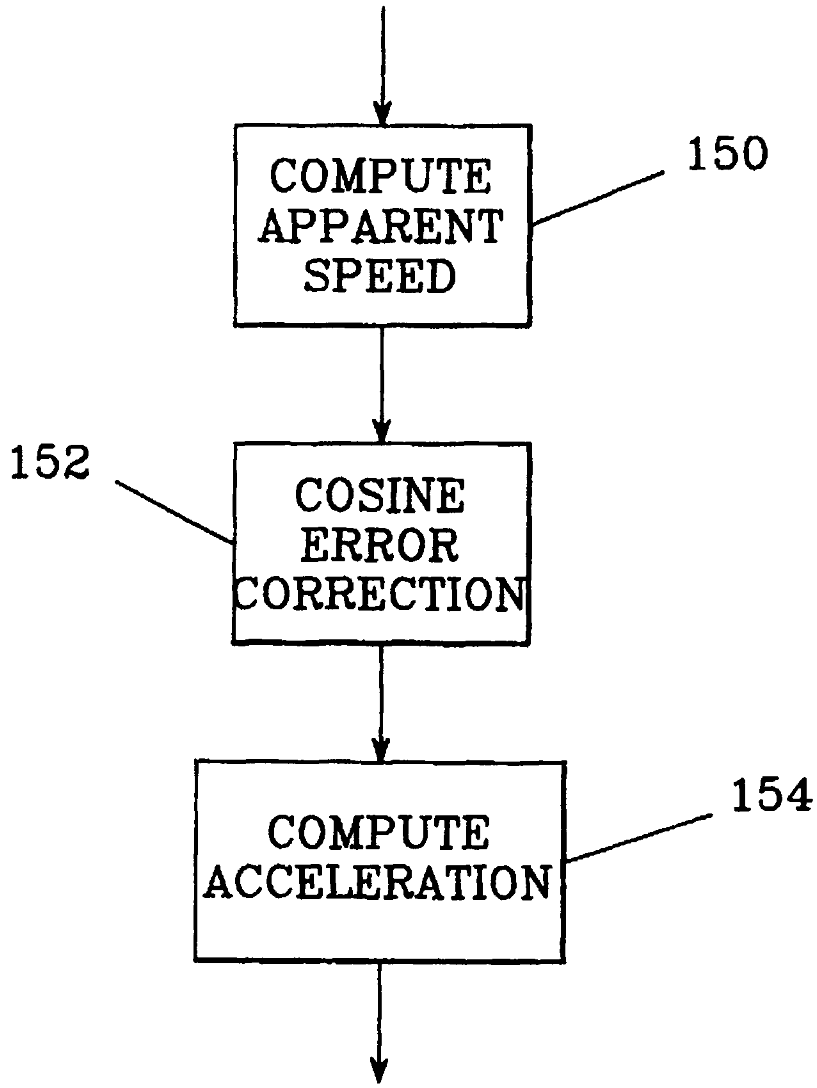

COMPUTE APPARENT SPEED
150
152
COSINE ERROR CORRECTION
COMPUTE ACCELERATION
154

FIG. 6

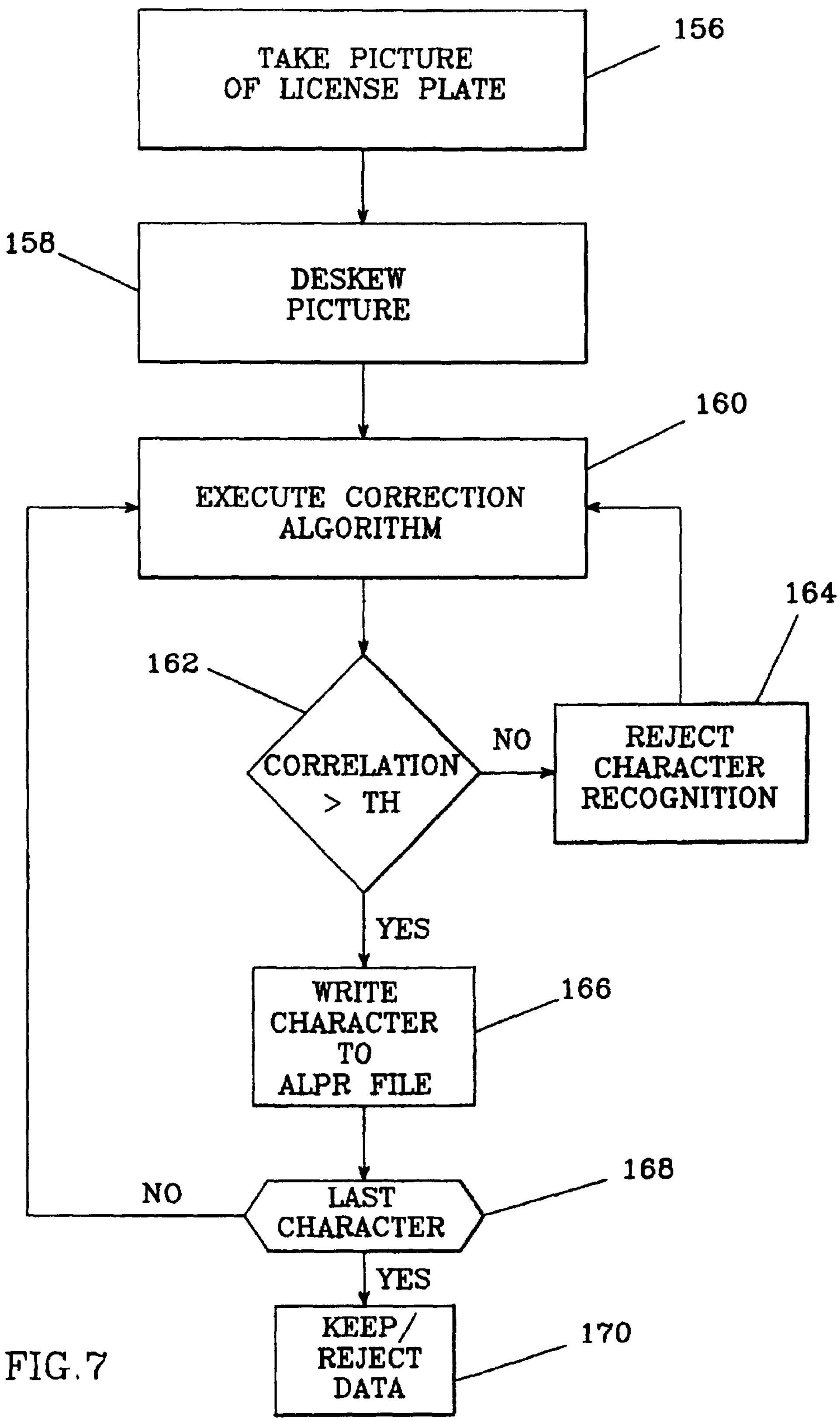

TAKE PICTURE OF LICENSE PLATE
156
158
DESKEW PICTURE
160
EXECUTE CORRECTION ALGORITHM
164
162
CORRELATION > TH
NO
REJECT CHARACTER RECOGNITION
YES
WRITE CHARACTER TO ALPR FILE
166
168
NO
LAST CHARACTER
YES
KEEP/ REJECT DATA
170

FIG. 7

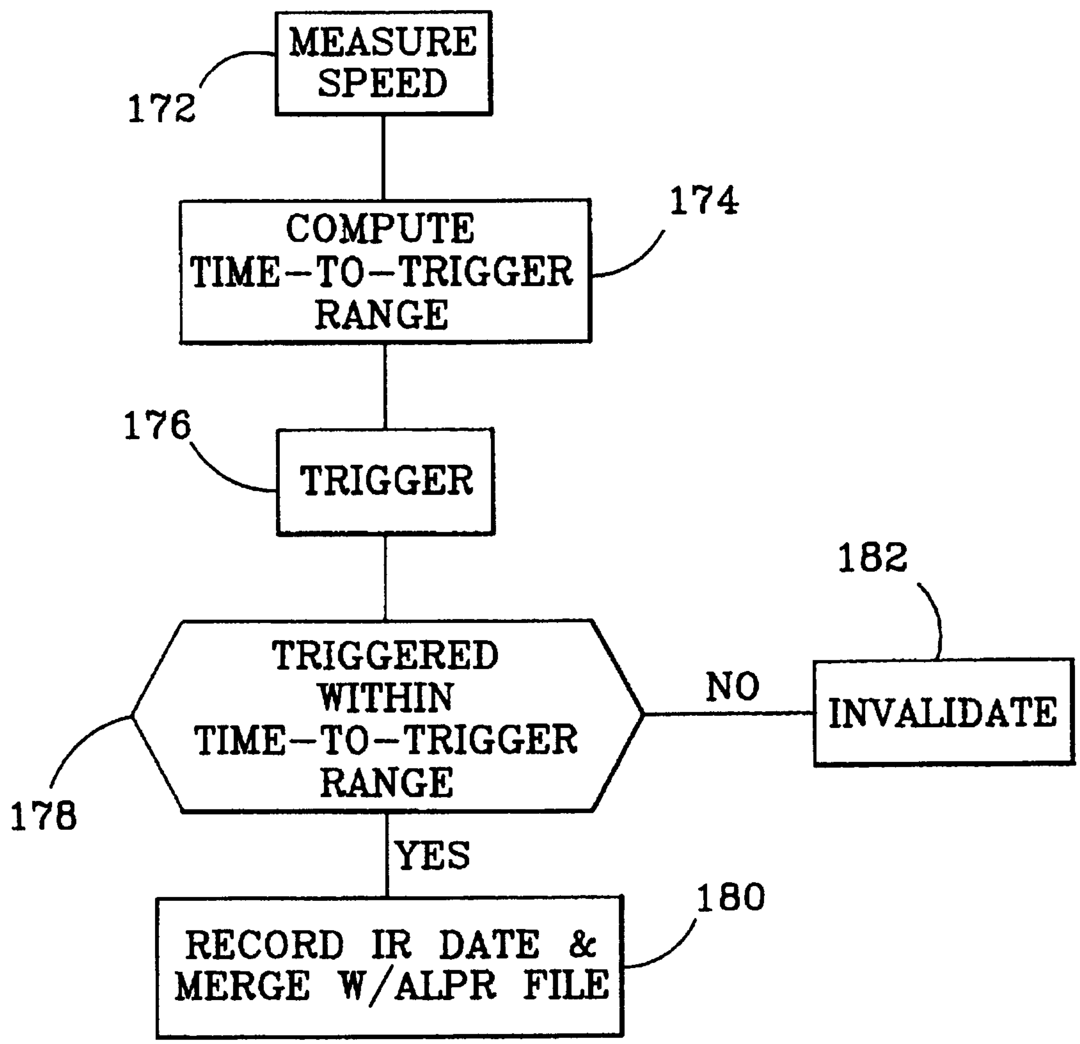

MEASURE SPEED
172
COMPUTE TIME–TO–TRIGGER RANGE
174
176
TRIGGER
182
TRIGGERED WITHIN TIME–TO–TRIGGER RANGE
NO
INVALIDATE
178
YES
180
RECORD IR DATE & MERGE W/ALPR FILE

FIG.8

UNMANNED INTEGRATED OPTICAL REMOTE EMISSIONS SENSOR (RES) FOR MOTOR VEHICLES

Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.

CROSS-REFERENCE TO RELATED [APPLICATION] *APPLICATIONS*

This *application is a divisional reissue application of U.S. patent application Ser. No. 09/708,713, filed Nov. 9, 2000 (issued as U.S. Pat. No. Re. 40,767 on Jun. 23, 2009), which is a continuation of U.S. patent application Ser. No. 09/521,858, filed Mar. 9, 2000 (abandoned), which is a Reissue of U.S. patent application Ser. No. 08/739,487, filed Oct. 26, 1996 (which issued as U.S. Pat. No. 5,726,450 on Mar. 10, 1998). Additionally this* application is related to *U.S. patent* application Ser. No. 08/318,566, entitled "Optical Sensing Apparatus for Remotely Measuring Exhaust Gas Composition of Moving Motor Vehicles," filed Oct. 5, 1994, and [assigned to Santa Barbara Research Corporation, the assignee of the present invention] *issued as U.S. Pat. No. 5,591,975, issued Jan. 7, 1997.*

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to the monitoring of environmental pollution, and more specifically to an unmanned integrated RES for remotely monitoring the exhaust gas composition of moving motor vehicles.

2. Description of the Related Art

Environmental pollution is a serious problem which is especially acute in urban areas. A major cause of this pollution is exhaust emissions from automotive vehicles. Official standards have been set for regulating the allowable amounts of pollutants species in automobile exhausts, and in some areas, periodic inspections or "smog checks" are required to ensure that vehicles meet these standards.

Anti-pollution devices which are required equipment on newer vehicles accomplish their intended purpose of reducing pollution in the vehicle exhaust to within prescribed levels. However, some older vehicles and special types of vehicles are exempt from inspections. Furthermore, some vehicle owners with mechanical expertise can perform whatever servicing is necessary to place their vehicles in condition to pass required inspections, and subsequently remove anti-pollution devices and/or return the vehicles with an attendant increase in pollutant emissions for normal use. The relatively small number of noncomplying vehicles generate a disproportionately large amount of pollution.

As a result, an anti-pollution program which depends entirely on mandatory periodic inspections performed at fixed facilities is inadequate. It is necessary to identify vehicles which are actually operating in violation of prescribed emission standards, and either require them to be placed in conformance with the standards or be removed from operation.

Manned RESs are now used to augment the periodic inspection program to identify vehicles that are in violation of the emissions standards. In general, RES are a nonobtrusive and cost-effective means for identifying the high pollution emitting vehicles and notifying the owner to take corrective action in a timely manner. The Smog Dog™ RES produced by Santa Barbara Research Center, the assignee of the present invention, includes a source and a receiver that are mounted on respective tripods and positioned on opposite sides of a road, a video camera and speed sensor that are mounted on a tripod that is positioned about 50 feet up the road in the direction of oncoming traffic, a van that contains a computer, data storage, power sources, calibration gas, and a video monitor, and a technician.

The source projects an IR beam across the road to the receiver which continuously senses pollutant levels such as carbon monoxide (CO), carbon dioxide (CO_2), hydrocarbons (HC), water (H_2O), nitric oxide (NO_x) in the received IR beam. When a vehicle passes through the IR beam, a sensor triggers the receiver to write the pollutant levels for the vehicle's exhaust plume to a data file in the data storage. The beam is set at a height to detect either low profile vehicles (cars) or high profile vehicles (trucks), but not both. The video camera takes a picture of the passing vehicle and the computer executes a character recognition program to identify the plate, which is then appended to the data file. If the speed sensor determines that the vehicle's acceleration and/or speed exceed certain levels, indicating that the vehicle's emissions control equipment are disabled, the recorded data is invalidated.

One drawback of the SMOG Dog™ and the other known RES systems is that the components, i.e. the sensor, receiver, video camera/speed sensor, and the van, are discrete parts that are positioned over a relatively large area. The source and receiver are positioned on opposite sides of the road. For safety purposes, they must be set back from the edges of the road. The video camera/speed sensor are positioned up the road such that their detection angles with respect to the passing vehicles is sufficiently shallow, approximately 3 degrees, to provide an accurate acceleration estimate and a high confidence of plate recognition. This can cause mismatch errors between the emissions readings and the plate recognition. Also, there must be enough room to park the van. These spatial requirements limit the applicability of the known RES systems. Furthermore, the discrete components are expensive because they require their own tripod, power supply, and alignment mechanisms.

Another drawback is that the known RES must be continuously manned by a technician, which is very expensive. After initial set up and alignment, the technician monitors the equipment to protect it from vandalism, performs required maintenance, and puts the system away at the end of the day. For example, the components may fall out of alignment due to the vibrations caused by passing vehicles, the various lenses may become occluded or the calibration gas may run out. Furthermore, the technician controls the data gathering process. The technician periodically places the RES in calibration mode, puffs a calibration gas into the IR beam to calibrate the system and evaluates the results displayed on the video monitor to accept or reject the calibration. Thereafter, the technician places the RES in data gathering mode, puffs the calibration gas, and compares the computed pollutant levels to the known levels of the calibration gas to accept or reject the verification of the calibration. During data gathering, the technician monitors both the signal levels of the exhaust plumes and the ambient air to determine whether the system has gone out of calibration or has a mechanical error. The technician also verifies the results of the plate recognition system.

U.S. Pat. No. 5,418,366 "IR-Based Nitric Oxide Sensor Having Water Vapor Compensation" issued May 23, 1995 discloses a specific receiver configuration having three channels for measuring a NO transmission, a water transmission, and a reference transmission, respectively, that are combined to give the effective NO transmission value. U.S. Pat. No. 5,210,702 "Apparatus for Remote Analysis of Vehicle Emissions" issued May 11, 1993 discloses a specific receiver configuration in which the ultraviolet beam is separated from the IR beam to sense the NO levels, and the IR beam is split into a plurality of components to measure CO, CO_2, HC and H_2O. Both systems use discrete source and receiver components placed on opposite sides of a road, a camera mounted on a tripod up the road, and a van for housing the control electronics, and require a technician to set the system up, calibrate the system, control the data gathering process, and pack it up at the end of the day.

In 1992 Remote Sensing Technologies (RST) experimented with a double-pass RES system called the RSD1000 in which a van housed both the source and the receiver and the video camera was suspended from a 20 foot boom. The IR beam was reflected off a mirror on the opposite side of the road back to the receiver. RST's system did not include the plate recognition or speed sensing capabilities, and never worked well enough for commercial exploitation. As a result, RST developed a one-pass system with the source and receiver on opposite sides of the road.

SUMMARY OF THE INVENTION

In view of the above problems, the present invention provides an unmanned integrated RES that reduces cost and simplifies operation.

This is accomplished by integrating each of the RES's components except the reflector into a single console that is positioned at the side of a road and providing a CPU that controls calibration, verification and data gathering. The source and receiver are preferably stacked one on top of the other such that the IR beam traverses a low and high path as it crosses the road. This allows the RES to detect both low and high ground clearance vehicles. To maintain the vehicle processing and identification throughput, the speed sensor and ALPR detect the passing vehicles at steep angles, approximately 20 to 35 degrees. In a preferred system, a manned control center communicates with a large number of the unmanned integrated RES to download emissions data, perform remote diagnostics, and if necessary, dispatch a technician to perform maintenance on a particular RES.

These and other features and advantages of the invention will be apparent to those skilled in the art from the following detailed description of preferred embodiments, taken together with the accompanying drawings, in which:

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a diagram of an remote emissions sensing system in which a plurality of unmanned integrated RESs record vehicle emissions and communicate with a central unmanned control center;

FIG. **2** is a perspective view of one of the unmanned integrated RESs shown in FIG. **1**;

FIG. **3** is a diagram of the source shown in FIG. **2**;

FIG. **4** is a diagram of the receiver shown in FIG. **2**;

FIG. **5** is a block diagram of the automated control processes executed by the control CPU shown in FIG. **2**;

FIG. **6** is a flowchart illustrating the operation of the speed sensor shown in FIG. **2**;

FIG. **7** is a flowchart illustrating the operation of the automated license plate reader (ALPR) shown in FIG. **2**; and

FIG. **8** is a flowchart illustrating the coordination of the speed sensor and the ALPR shown in FIG. **2**.

DETAILED DESCRIPTION OF THE INVENTION

The present invention provides an emissions sensing system that includes a plurality of unmanned integrated RES. A manned control center communicates with a large number of the RESs to download emissions data, perform remote diagnostics, and, if necessary, dispatch a technician to perform maintenance on a particular RES. The source, receiver, speed sensor, automated license plate reader (ALPR), gas canister, power supplies, and computer are integrated into a console that can be positioned at the side of a road either permanently or for an extended period of time. A reflector is positioned on the other side of the road to reflect the IR beam back to the receiver. The source and receiver are preferably stacked one on top of the other such that the IR beam traverses a low and high path as it crosses the road. This allows the RES to detect both low and high ground clearance vehicles. To maintain the vehicle processing and identification throughput of the known systems, the speed sensor and ALPR detect the passing vehicles at steep angles, approximately 20 to 35 degrees. This has the beneficial effect of reducing the number of mismatches between pollutant readings and vehicle identification. Furthermore, data gathering control including calibration, verification, and data gathering are automated. This eliminates the need for an on site technician, which further reduces cost.

As shown in FIG. **1**, a remote emissions sensing system **10** includes a plurality of unmanned integrated RESs **12** that are placed at different positions in a network of roads **14**, a manned control center **16** and a two-way communications channel **18**. The communications channel shown is a wire-to-wire telephone network. Alternately, a cellular or satellite network could be used.

The RES **12** and a reflector **22** are placed on opposite sides of the road **14** and aligned such that the RES's IR beam **24** is reflected back to the RES **12**. When a vehicle **26** passes through the IR beam **24**, the RES **12** writes the pollutant levels from the vehicle's exhaust plume **28** to a data file and appends the vehicle's license plate number. If the vehicle's speed or acceleration are too high, indicating that the vehicle's emissions control have been disabled, the data is invalidated.

The RESs **12** are automated to maintain calibration and, if repeated recalibration fails, to notify the control center **16**. The control center performs remote diagnostics to identify the cause of the calibration failure and, if possible, to correct the problem. Otherwise a technician is dispatched to the RES **12**. The RESs **12** periodically download the gathered emissions data to the control center **16**.

As shown in FIG. **2**, all of the components of the RES **12**, except for the reflector **22**, are enclosed in a console **30**, suitably **5'** high, **3'** wide, and **2'** deep. The reflector **22** such as a piece of black aluminum that is opaque in the visible spectrum is attached to the guard rail at the side of the road, for example. A source **32** emits the IR beam **24** that crosses the road and reflects off of the reflector **22** back to a receiver **34**. The receiver **34** samples the radiation levels in the beam **24** at various wavelengths. Because of the presence of NO, water vapor, CO_2, CO, HC and other molecular species within the exhaust plume **28**, the IR beam **24** is partially absorbed at the various wavelengths when it passes through the plume. A computer **36** includes a data processing central processing unit (CPU) **38** that computes the composition of the ambient air, and when a vehicle passes by, computes the composition of the plume **28** in terms of the percentage or concentrations of the constituents NO, CO_2, CO and HC based on the sampled radiation levels. The computation of the composition is well known in the art and is thus omitted.

A trigger circuit **40** in the receiver **34** provides a trigger signal when a vehicle passes through the beam **24**. The circuit responds to the sequential condition of the received signal going to zero, "beam block" followed by the received signal returning to a valid emissions level, "beam unblock." Placing the source **32** on top of the receiver **34** causes the IR beam **24** to traverse an upper path **42** across the road and to return along a lower path **44** to the receiver. As a result, the circuit will trigger on either low or high ground clearance vehicles. The trigger signal is fed to the data processing CPU **38** causing it to write the composition of the plume to a data file on a hard disk **46**.

A vehicle identification system identifies the passing vehicle and appends the identification to the data file. The currently preferred approach is an automated license plate reader (ALPR) system that includes a video camera **48** that takes a picture of the vehicle's license plate **50** in response to the trigger signal and a identification CPU **52** that executes a character recognition algorithm to extract the plate number. Alternately, the vehicles could transmit identification codes that would be detected as the vehicles pass by the RES.

The video camera takes the picture at an angle ρ with respect to the road. The shallower the angle, the easier it is for the character recognition algorithm to extract the plate number. However, the shallower the angle, the farther the vehicle is past the RES when its plate is read. This increases the chance of mismatching the vehicle identification to the wrong data file. Furthermore, this reduces the number of vehicles that can be tested in a given time, i.e. the vehicle throughput.

An optional speed sensor system determines the acceleration of an oncoming vehicle and invalidates the subsequently measured data if the acceleration is too high. The speed sensor system preferably includes an oblique angle radar **54** that detects oncoming vehicles and a CPU **56** that computes the vehicle's acceleration. Alternately, a LIDAR system, piezeo or pneumatic cables, or an optical sensor could be used to measure the vehicle's acceleration. Similar to the video camera, the slant radar detects the oncoming vehicle at an angle with respect to the road. The shallower the angle, the more accurate the estimate of the acceleration using known techniques but the lower the vehicle throughput. As a result, the known ALPR and speed/acceleration algorithms are modified as shown in FIGS. **7** and **6**, respectively, to enable steep angle detection.

The RES **12** includes a number of secondary components that are required to support the data gathering process. A power supply **58** supplies power to the source **32**, receiver **34**, video camera **48**, radar **54**, and the CPUs. A pair of fans **60** cool the electrical systems in the RES **12**. A pair of vents **62** vent the source and calibration gas to the atmosphere. An external computer port **64** allows a service technician to connect a laptop computer to the RES **12** to access the CPUs and perform diagnostics.

An automated control system controls the data gathering process for the RES **12**. The primary function of the control system is to maintain calibration so that the recorded data is reliable. A gas canister **66** contains calibration gas that has a known composition of pollutants. When actuated, the gas canister **66** emits a puff of calibration gas in front of the source. This is used to both recompute the calibration curves and to verify the calibration.

The RES **12** can lose calibration for a number of reasons. First, the ambient conditions can change. For example, the CO_2 levels typically rise during the day, the HC levels near industrial plants will also rise during the day, heavy traffic will increase the background pollutant levels, and rain will destroy the IR signature. Second, mechanical problems such as the gas bottle being empty, the source being worn out, or a stolen reflector will result in a loss of calibration. Another common source of signal degradation is a dirty receiver lens. In known systems, when the technician notices signal degradation he manually cleans the lens on the receiver. In the automated RES, a multi-position lens cover **68** is placed in front of the receiver lens, and indexed when the signal levels degrade.

A control CPU **70**, as detailed in FIG. **5**, automates the calibration, verification, and data gathering processes by controlling the actuation of the gas canister **66** and the indexing of the multi-position lens cover **68** and monitoring the compositions of the exhaust plume and ambient air. When repeated attempts to calibrate the system fail, the CPU **70** sends a help mess over the communications channel **18** shown in FIG. **1** via a communications port **72**.

As shown in FIG. **3**, the source **32** includes an IR source **74**, preferably a broadband IR source such as a glow bar, that has a significant IR radiation output in the range of approximately 3 micrometers to approximately 6 micrometers. The IR source **74** provides a beam **24** that may optionally be passed through a chopper **76** (nominally 200 cycles per second) and a beam former **78**, such as a parabolic reflector. In the preferred embodiment, the receiver **34** (shown in detail in FIG. **4**) uses solid state detectors which must be turned on and off in order to detect the radiation levels. As a result, the chopper **76** is positioned in the path of the IR beam to block and unblock the beam and thereby switch the detectors on and off.

In the preferred embodiment, the chopper **76** is positioned at the IR source, which enables the system to distinguish infrared radiation emitted by the source from that emitted by the vehicle exhaust. When the chopper blocks the beam, the receiver measures the infrared radiation emitted from the plume. The data processing CPU calculates the peak-to-peak signal which removes the quiescent levels of the receiver as well as the interference from the vehicle exhaust. Thus, the measurements of the transmission levels are more accurate. Alternately, the chopper **76** can be positioned at the receiver. However, in this configuration the constituent measurements can be distorted by irradiance from the plume itself.

As shown in FIG. **4**, the receiver **34** includes the multi-positioned lens cover **68** that is periodically indexed to provide a clean surface for receiving the IR beam **24**. The multi-position lens cover **68** is preferably an IR transmissive sheet on a roller. The IR beam is applied to a plurality n of narrow band filters **80**, where n is equal to a number of measurement channels. Each filter **80** is selected so as to pass a predetermined narrow band of wavelengths to an associated one of a plurality of IR detectors **82**. The IR detectors include photosensitive elements which are integrally fabricated on a substrate. The elements are preferably photoconductive and formed of mercury cadmium telluride (HgCdTe or HCT), whereas the substrate is cadmium zinc telluride (CdZnTe).

Each detector **82** outputs an electrical signal corresponding to the radiation level at its wavelength to an amplifier **84**. An n channel analog to digital (A/D) converter **86** digitizes the amplified signals and outputs them to the data processing CPU **38** shown in FIG. **2**. A suitable cooler **88**, such as a thermo-electric (TE) device, is employed for cooling those types of IR detectors **82** which are required to be cooled to an operating point that is below ambient temperature.

A beam integrator lens **90** is preferably placed between the lens cover **68** and the filters **80** to homogenize the beam **24** after propagation through the plume to remove the spatial and temporal variations of the constituent concentrations so that the detected signals are synchronized. The optical intensity or energy that is incident on the photodetectors **82** is substantially uniform throughout the cross-section of the homogenized beam **24**. This ensures that the same homogenized or averaged scene is sensed by the photodetectors **82**, and substantially increases the accuracy of the measurement by reducing the spatial and temporal variance of the constituent concentrations by over an order of a magnitude. The beam integrator lens enables synchronous operation of the photodetectors.

In a presently preferred embodiment of this invention there are six spectral measurement channels. These are an NO spectral channel (having a filter **80** with a passband centered on 5.26 μm), an H_2O spectral channel (having a filter **80** with a passband centered on 5.02 μm), a first reference, or CO_2 spectral channel (having a filter **80** with a passband centered on 4.2 μm), a CO spectral channel (having a filter **80** with a passband centered on 4.6 μm), a HC spectral channel (having a filter **80** with a passband centered on 3.3 μm) and a second reference (REF) spectral channel (having a filter **80** with a passband centered on 3.8 μm). Additional channels to measure other pollutants can also be added if desired.

In general, the NO spectral channel is located near resonant absorption peaks in the vicinity of 5.2 μm; the water vapor spectral channel is in a region of strong water absorption where fundamental lines do not saturate; the first reference spectral channel is employed for normalizing the pollutants to the normal combustion products, i.e., CO_2; and the second reference (REF) spectral channel is provided at a region in which no atmospheric or automotive emissions gases absorb.

The REF spectral channel compensates the other five spectral channels for variations caused by: (a) fluctuations in the output of the IR source **74** shown in FIG. **3** during the passage of the vehicle; (b) particulate matter in the form of road dust; (c) particulate matter in the exhaust gas plume **28**; (d) infrared radiation emitted from the exhaust plume, and any other factors that may reduce the amount of illumination reaching the detectors **82**. The REF spectral channel thus operates to provide a baseline output which is independent of the molecular species (NO, H_2O, CO_2, CO and HC) being measured. The output of the second REF spectral channel is used to normalize, such as by dividing, the five molecular species spectral channels.

FIG. **5** is a flowchart of the automated control process executed by the control CPU **70** shown in FIG. **2** in cooperation with the manned control center **16** shown in FIG. **1**. Once the RES is set up, the CPU **70** boots the system to a calibration mode (step **92**) and uses the speed and acceleration data provided by the CPU **56** to determine whether a vehicle is approaching (step **94**). If so, the CPU **70** waits (step **96**) until no vehicles are in range and performs a calibration (step **98**). The CPU **70** directs the gas canister to emit a puff of calibration gas so that the data processing CPU uses the radiation levels for the various pollutants and their known concentrations to recompute a set of calibration curves. Thereafter, the CPU **70** switches to a measurement mode (step **100**).

Once in measurement mode, the CPU **70** again determines whether a vehicle is approaching (step **102**), waits until no vehicle is in range (step **104**), and performs a puff-in-vehicle (PIV) test (step **106**) to verify the calibration. The CPU **70** directs the gas canister to emit another puff of calibration gas so that the data processing CPU uses the calibration curves to compute a composition for the calibration gas (step **108**). If the composition deviates from a known reference composition of the calibration gas then the calibration is rejected. If calibration has failed repeatedly (step **110**), for example 10 times in a row, the CPU **70** directs the RES to notify the control center (step **112**). Otherwise the CPU **70** repeats steps **92** through **108** to recalibrate the system and verify the calibration.

When the composition calculated in step **108** is close enough to the reference composition, the calibration is accepted and data collection initiated (step **114**). The data processing CPU will generate an error code 9999 when the data, i.e. the sensed radiation levels, is no good. Random and infrequent bad data is expected as part of the sensing process. However, a high percentage of bad data is indicative of a either a system problem such as an occluded lens, beam misalignment or mechanical problems in the source or the system being out of calibration. The CPU **70** monitors the data (step **116**), and if the frequency of error codes exceeds a threshold, initiates recalibration by returning control to step **104**. Otherwise, the data processing CPU continues gathering data (step **118**).

Because the ambient conditions can change over time, the CPU **70** periodically verifies the last calibration (step **120**) by returning control to step **102**. The system continues gathering data (step **122**) in the measurement mode while the CPU **70** monitors the data processing CPU to make sure that it is sampling the radiation levels and computing compositions (step **124**). If not, the CPU **70** assumes that the system software has failed, power cycles the system (step **126**) to reboot the software, performs a calibration (step **128**), and determines whether the calibration was effective (step **130**). If power cycling has restored the system, control returns to step **102** to verify the calibration. Otherwise, the CPU **70** causes the RES to notify the control center (step **112**).

If the data processing CPU is receiving and processing the data in step **124**, the CPU **70** monitors the ambient signal levels (radiation levels or compositions) (step **132**). If the ambient signal levels are close enough to a set of reference values (step **134**), for example, the values measured at the last calibration, then data gathering continues at step **114**. If the signal levels have deviated, the CPU **70** indexes the lens cover **68** shown in FIG. **4** (step **136**). Oftentimes signal deviation is due to dirt or exhaust building up on the lens of the receiver. Thereafter, the CPU **70** checks to determine whether the ambient signal levels have been corrected (step **138**). If so, the data processing CPU continues gathering data (step **114**). Otherwise, the CPU **70** performs a calibration (step **140**) and a PIV (step **142**). If the calibration is accepted, data gathering continues. If not, the RES notifies the control center (step **112**).

When the RES notifies the control center (step **112**), a technician at the control center executes remote diagnostics over the communications channel to identify the problem (step **144**). If the system can be fixed remotely (step **146**), control is returned to CPU **70** to gather data. Otherwise, a service technician is dispatched to the RES (step **148**).

In order to maintain the same vehicle throughput as the known RES systems, the integrated RES radar **54** and video camera **48** shown in FIG. **2** must detect the approaching and passing vehicles, respectively, at a steep angle, approximately 20 to 35 degrees. As shown in FIG. **6**, the CPU **56** computes the apparent speed measured by the radar **54** shown in FIG. **2** (step **150**) and then corrects for what is called "cosine error" (step **152**) by multiplying the apparent speed by the cosine of the detection angle (cos θ) to produce an accurate reading of the oncoming vehicle's true speed. In step **154**, the CPU computes the vehicle's acceleration. The vehicle's speed and acceleration are used to determine whether the vehicle's emissions systems are disabled and can be used to predict when the vehicle should trigger data acquisition to reduce mismatch between recorded emissions and the identified license plate as detailed in FIG. **8**.

As shown in FIG. **7**, the preferred ALPR system deskews the picture of the vehicle's license plate to compensate for the steep detection angle prior to executing a character recognition algorithm. When triggered, the video camera **48** takes a picture of the passing vehicle's license plate at a steep angle (ρ), approximately 20 to 35 degrees (step **156**). The system's CPU **52** (shown in FIG. **2**) digitizes the picture into a digital image and transforms the skewed image into a normalized image, as if the picture had been taken at a shallow angle of approximately zero degrees (step **158**). The steep-to-shallow angle transformation may be achieved using an affirm transformation, for example.

The CPU then executes a correlation algorithm on the first character in the normalized image to generate a correlation value for each character in an alpha-numeric set and selects the character with the highest correlation value (step **160**). Thereafter, the correlation value of the selected character is compared to a recognition threshold. e.g. 90% (step **162**). If the correlation value is less than the threshold, recognition is rejected (step **164**). If the correlation value exceeds the threshold, the character is written into the ALPR file which is appended to the recorded emissions data file (step **166**). The correlation algorithm is repeated for each character in the license plate until all the characters have been recognized or rejected (step **168**). If only one or two of the characters in the license plate are rejected, the plate may still be uniquely identifiable. If so, the partial plate can be appended to the emissions data and recorded. However, if too many characters in the entire license plate are rejected, then the entire plate recognition is rejected and the recorded emissions data is not reported (step **170**).

A common problem in known RES systems is a mismatch between the recorded emissions data and the license plate, i.e. the wrong car is matched to the offending emissions. The steep angles used by the radar and video camera reduce the frequency of mismatches to some extent by confining the area in which they look for a passing vehicle. As illustrated in FIG. **8**, the mismatch frequency can be further reduced by combining the speed and acceleration information provided by the radar with the trigger signal. In step **172**, the data processing CPU computes the speed and acceleration of an approaching vehicle as described in FIG. **6**. The CPU uses this information and the distance to the vehicle to estimate a time-to-trigger range(step **174**). When the vehicle passes through the IR beam, the CPU records the trigger time (step **176**) and determines whether it falls within the time-to-trigger range (step **178**). If the trigger falls within the range, the CPU merges the emissions data with the license plates (step **180**). Otherwise, the CPU invalidates the data (step **182**).

While several illustrative embodiments of the invention have been shown and described, numerous variations and alternate embodiments will occur to those skilled in the art. Such variations and alternate embodiments are contemplated, and can be made without departing from the spirit and scope of the invention as defined in the appended claims.

We claim:

[**1**. An unmanned optical emissions sensor for sensing a gas mixture composition of an exhaust plume of a motor vehicle travelling along a road, comprising:

a source for radiating a beam of light along a path across a road such that the beam passes through the exhaust plume of a passing vehicle and otherwise passes through ambient air;

a receiver for sampling radiation levels at a plurality of predetermined wavelengths from the beam;

a canister for emitting a puff of calibration gas in the path of the beam between the source and the receiver, said calibration gas having a known reference composition at the predetermined wavelengths;

a data processing computer for computing a gas mixture composition from the sensed radiation levels in accordance with stored calibration curves;

a trigger device that produces a trigger signal when a vehicle passes through the beam causing the data processing computer to record the gas mixture composition of the vehicle's exhaust plume for a period of time;

an automated control computer that

a) calibrates the data processing computer by directing the canister to emit a puff of calibration gas, whereby the data processing computer recomputes the calibration curves in accordance with the known reference composition;

b) verifies the calibration by directing the canister to emit a puff of calibration gas, whereby the data processing computer computes a test composition from the radiation levels and accepts the calibration when the test composition is close enough to the known reference composition and otherwise rejects the calibration and initiates recalibration; and

c) monitors the gas mixture composition of the ambient air to control recalibration of the data processing computer; and

a vehicle identification device that responds to the trigger signal by recording a vehicle identification for the passing vehicle.]

[**2**. The unmanned optical emissions sensor of claim **1**, further comprising:

a multi-position lens cover on the receiver, said automated control computer indexing the position of the lens cover when the gas mixture composition of the ambient air deviates from an ambient reference level by more than a specified threshold and initiates recalibration if the deviation remains greater than the specified threshold.]

[**3**. The unmanned optical emissions sensor of claim **1**, wherein the automated control computer monitors the gas mixture composition of the vehicle's exhaust plume to control reverification of the calibration.]

[**4**. The unmanned optical emissions sensor of claim **1**, wherein the automated control computer monitors a time from the last calibration and when the time exceeds a mandatory recalibration period it initiates another calibration.]

[**5**. The unmanned optical emissions sensor of claim **1**, wherein the automated control computer monitors the data processing computer and power cycles the emissions sensor when the data processing computer fails to produce gas mixture compositions.]

[**6**. The unmanned optical emissions sensor of claim **1**, further comprising:

a manned control center; and

a communications channel for communication between the automated control computer and the manned control center, said automated control computer responding to repeated calibration rejections by transmitting a help message to the manned control center, which in turn responds by performing diagnostics to determine a cause for the calibration rejection and then either remedy the cause remotely or dispatch a technician to remedy the cause on site.]

[**7**. The unmanned optical emissions sensor of claim **1**, further comprising:

a vehicle detector for sensing an oncoming vehicle and computing its acceleration, said data processing computer disabling the recordation of the composition of the vehicle's exhaust plume when the acceleration exceeds a threshold.]

[**8**. The unmanned optical emissions sensor of claim **7**, wherein the vehicle detector compute's the vehicle's speed and computes a time-to-trigger range from the vehicle's measured speed and acceleration, said data processing computer disabling the recordation of the composition of the vehicle's exhaust plume when triggering occurs outside the time-to-trigger range.]

[**9**. The unmanned optical emissions sensor of claim **7**, wherein said source and said receiver are placed on the same side of the road, further comprising:

- a reflector that is positioned on the other side of the road such that the beam emitted by the source reflects off of the reflector and back to the receiver.]

[**10**. The unmanned optical emissions sensor of claim **9**, further comprising:

- a single console that contains the source, the receiver, the canister, the data processing computer, the automated control computer, the vehicle identification device, and the vehicle detector.]

[**11**. The unmanned optical emissions sensor of claim **10**, wherein the vehicle identification device comprises an automated license plate reader (ALPR) that reads the vehicle's license at an angle of at least 20 degrees and said vehicle detector senses the oncoming vehicle at an angle of at least 20 degrees to maintain a vehicle throughput.]

[**12**. The unmanned optical emissions sensor of claim **10**, wherein one of said source and said receiver is positioned above the other so that the beam traverses the road in a low path in one direction and in a high path in the other direction so that the trigger device will trigger on both high and low ground clearance vehicles.]

[**13**. An integrated optical emissions sensor for sensing a gas mixture composition of an exhaust plume of a motor vehicle travelling along a road, comprising:

- a single console that is positioned at one side of the road;
- a vehicle detector in said console for sensing an oncoming vehicle and computing its acceleration;
- a source in said console for radiating a beam of light along a path across the road such that the beam passes through the exhaust plume of a passing vehicle and otherwise passes through ambient air;
- a reflector that is positioned on the other side of the road such that the beam reflects off of the reflector and back to the console;
- a receiver in said console sampling radiation levels at a plurality of predetermined wavelengths from the beam;
- a data processing computer in said console for computing a gas mixture composition from the sensed radiation levels in accordance with stored calibration curves;
- a canister in said console for emitting a puff of calibration gas in the path of the beam between the source and the receiver to recompute the calibration curves;
- a trigger device in said console that produces a trigger signal when a vehicle passes through the beam causing the data processing computer to record the gas mixture composition of the vehicle's exhaust plume for a period of time, said data processing computer disabling the recordation of the composition of the vehicle's exhaust plume when the acceleration exceeds a threshold; and
- a vehicle identification device in said console that responds to the trigger signal by recording a vehicle identification for the passing vehicle.]

[**14**. The unmanned optical emissions sensor of claim **13**, wherein the vehicle identification device comprises an automated license plate reader (ALPR) that reads the vehicle's license at an angle of at least 20 degrees and said vehicle detector senses the oncoming vehicle at an angle of at least 20 degrees to maintain a vehicle throughput.]

[**15**. The unmanned optical emissions sensor of claim **13**, wherein one of said source and said receiver is positioned above the other so that the beam traverses the road in a low path in one direction and in a high path in the other direction so that the trigger device will trigger on both high and low ground clearance vehicles.]

[**16**. The unmanned optical emissions sensor of claim **13**, wherein the vehicle detector compute's the vehicle's speed and computes a time-to-trigger range from the vehicle's measured speed and acceleration, said data processing computer disabling the recordation of the composition of the vehicle's exhaust plume when triggering occurs outside the time-to-trigger range.]

[**17**. The unmanned optical emissions sensor of claim **13**, wherein said calibration gas has a known reference composition at the predetermined wavelengths, further comprising an automated control computer that

- a) calibrates the data processing computer by directing the canister to emit a puff of calibration gas, whereby the data processing computer recomputes the calibration curves in accordance with the known reference composition;
- b) verifies the calibration by directing the canister to emit a puff of calibration gas, whereby the data processing computer computes a test composition from the radiation levels and accepts the calibration when the test composition is close enough to the known reference composition and otherwise rejects the calibration and initiates recalibration; and
- c) monitors the gas mixture composition of the ambient air to control recalibration of the data processing computer.]

[**18**. A remote emissions sensing system sensing gas mixture compositions of exhaust plumes for motor vehicles traveling along a network of roads, comprising:

- a plurality of unmanned integrated optical emissions sensors positioned at different places in the network on a side of the road, each emissions sensor comprising:
  - a console;
  - a vehicle detector in said console for sensing an oncoming vehicle and computing its acceleration;
  - a source in said console for radiating a beam of light along a path across the road such that the beam passes through the exhaust plume of a passing vehicle and otherwise passes through ambient air;
  - a reflector that is positioned on the other side of the road such that the beam reflects off of the reflector and back to the console;
  - a receiver in said console that samples radiation levels at a plurality of predetermined wavelengths from the beam;
  - a data processing computer in said console for computing a gas mixture composition from the sensed radiation levels in accordance with stored calibration curves;
  - a canister in said console for emitting a puff of calibration gas in the path of the beam between the source and the receiver, said calibration gas having a known reference composition at the predetermined wavelengths;
  - a trigger device in said console that produces a trigger signal when a vehicle passes through the beam causing the data processing computer to record the gas

mixture composition of the vehicle's exhaust plume for a period of time, said data processing computer invalidating the recordation of the composition of the vehicle's exhaust plume when the acceleration exceeds a threshold;

an automated control computer that

a) calibrates the data processing computer by directing the canister to emit a puff of calibration gas, whereby the data processing computer recomputes the calibration curves in accordance with the known reference composition;

b) verifies the calibration by directing the canister to emit a puff of calibration gas, whereby the data processing computer computes a test composition from the radiation levels and accepts the calibration when the test composition is close enough to the known reference composition and otherwise rejects the calibration and initiates recalibration; and

c) monitors the gas mixture composition of the ambient air to control recalibration of the data processing computer; and

a vehicle identification device in said console that responds to the trigger signal by recording a vehicle identification for the passing vehicle;

a manned control center; and

a communications channel for communication between the emissions sensors and the manned control center, said emissions sensors responding to repeated calibration rejections by transmitting a help message to the manned control center, which in turn responds by performing diagnostics to determine a cause for the calibration rejection and then either remedy the cause remotely or dispatch a technician to remedy the cause on site.]

[**19**. The unmanned optical emissions sensor of claim **18**, wherein the vehicle detector compute's the vehicle's speed and computes a time-to-trigger range from the vehicle's measured speed and acceleration, said data processing computer disabling the recordation of the composition of the vehicle's exhaust plume when triggering occurs outside the time-to-trigger range.]

[**20**. The unmanned optical emissions sensor of claim **18**, wherein the vehicle identification device comprises an automated license plate reader (ALPR) that reads the vehicle's license at an angle of at least 20 degrees and said vehicle detector senses the oncoming vehicle at an angle of at least 20 degrees to maintain a vehicle throughput.]

[**21**. The unmanned optical emissions sensor of claim **18**, wherein one of said source and said receiver is positioned above the other so that the beam traverses the road in a low path in one direction and in a high path in the other direction so that the trigger device will trigger on both high and low ground clearance vehicles.]

22. A system for monitoring emissions of moving motor vehicles comprising:

a plurality of remote emissions sensing devices deployed at a plurality of testing locations, said sensing devices automatically gathering emissions data on a plurality of moving vehicles; and

a central control, said central control connected to each of said plurality of remote emissions sensing devices via a communications channel, said central control receiving emissions data on the plurality of moving vehicles and performing remote diagnostics on said plurality of remote emissions sensing devices.

23. A method of monitoring vehicle emissions comprising:

gathering emissions data on moving motor vehicles at a plurality of testing locations using a plurality of remote emissions sensing devices;

downloading emissions data gathered by the remote emissions sensing devices to a central control; and

performing remote diagnostic checks of the remote emissions sensing devices from the central control.

24. The method of claim 23, wherein the step of performing remote diagnostic checks comprises remotely initiating repeated calibration attempts and analyzing returned data.

25. The method of claim 23, wherein the step of performing remote diagnostic checks comprises remote actuation of a mechanical part of at least one of the remote emission sensing devices.

26. The method of claim 25, wherein the mechanical part is a receiver lens cover.

27. A system for monitoring emissions of moving motor vehicles, comprising:

a first remote emissions sensing device deployed at a first testing location, the first remote emissions sensing device configured to gather emissions data from one or more moving motor vehicles driving past the first testing location;

a second remote emissions sensing device deployed at a second testing location that is located remotely from the first testing location, the second remote emissions sensing device configured to gather emissions data from one or more moving motor vehicles driving past the second testing location; and

a control center, located remotely from the first testing location and the second testing location, the control center in operative communication with the first remote emissions sensing device and the second remote emissions sensing device, and configured to:

(1) receive gathered emissions data from the first remote emissions sensing device and the second remote emissions sensing device; and

(2) perform remote diagnostics on the first remote emissions sensing device and the second remote emissions sensing device.

28. A method of monitoring emissions of moving motor vehicles, comprising:

receiving, at a control center, from a first remote emissions sensing device in operative communication with the control center and located remotely from the control center, emissions data gathered by the first remote emissions sensing device corresponding to one or more moving motor vehicles that drive past the first remote emissions sensing device;

receiving, at the control center, from a second remote emissions sensing device in operative communication with the control center and located remotely from the control center, emissions data gathered by the second remote emissions sensing device corresponding to one or more moving motor vehicles that drive past the second remote emissions sensing device, wherein the second remote emissions sensing device is located remotely from the first remote emissions sensing device; and

performing remote diagnostic checks of the first remote emissions sensing device and the second remote emissions sensing device from the control center.

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