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Schwarz et al.

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(54) **LOW-POWER VEHICLE DETECTION**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

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(63) Continuation of application No. 17/812,206, filed on Jul. 13, 2022, now Pat. No. 11,688,277, which is a

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(51) **Int. Cl.**

G08G 1/017	(2006.01)
G01D 4/00	(2006.01)
G07F 17/24	(2006.01)

(52) **U.S. Cl.**

CPC ***G08G 1/017*** (2013.01); ***G01D 4/002*** (2013.01); ***G07F 17/246*** (2013.01); *G01D 4/004* (2013.01); *Y02B 70/34* (2013.01); *Y04S 20/30* (2013.01)

(58) **Field of Classification Search**

CPC G08G 1/017; G08G 1/042; G01D 4/002; G01D 4/004; G07F 17/246; Y02B 70/34; Y04S 20/30; G07B 15/02; G06Q 20/145

See application file for complete search history.

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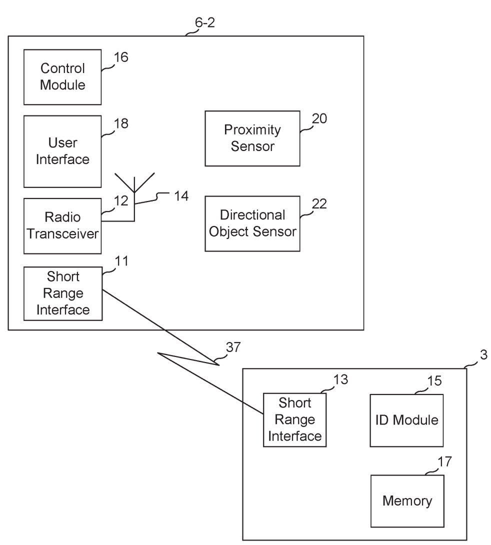
(57) **ABSTRACT**

A parking meter detects an object in proximity, based on a change in a proximity measurement at the meter, activates a directional sensor in response to detecting the object, receives sensor data at a meter processor from the directional sensor, wherein the received sensor data indicates a predetermined direction to the detected object relative to the meter. The parking meter determines a presence of the object, or lack thereof, in the predetermined direction based on the sensor data, and upon a positive determination of the presence of the object, stores an indication of the presence of the object along with a time of the positive determination.

27 Claims, 6 Drawing Sheets



Related U.S. Application Data

continuation of application No. 16/913,246, filed on Jun. 26, 2020, now Pat. No. 11,423,776, which is a continuation of application No. 16/383,203, filed on Apr. 12, 2019, now Pat. No. 10,741,064, which is a continuation of application No. 15/633,290, filed on Jun. 26, 2017, now Pat. No. 10,297,150, which is a continuation of application No. 14/811,641, filed on Jul. 28, 2015, now Pat. No. 9,728,085, which is a continuation of application No. 13/558,242, filed on Jul. 25, 2012, now Pat. No. 9,127,964.

(60) Provisional application No. 61/511,484, filed on Jul. 25, 2011.

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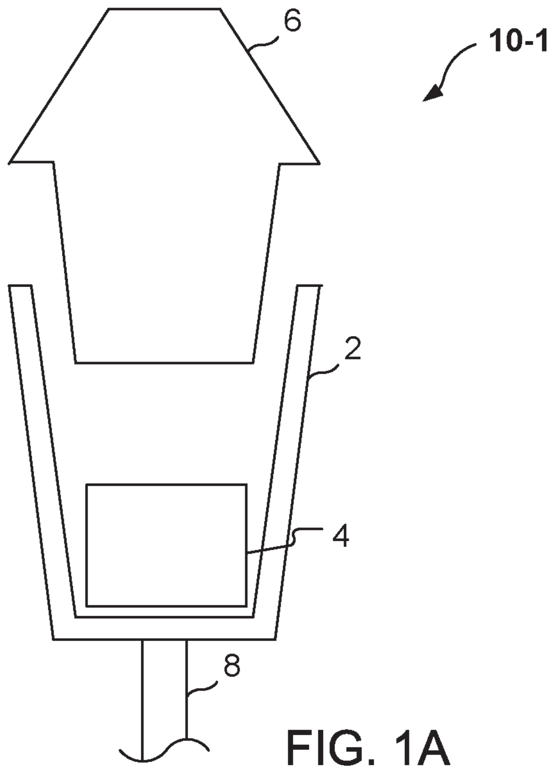


FIG. 1A

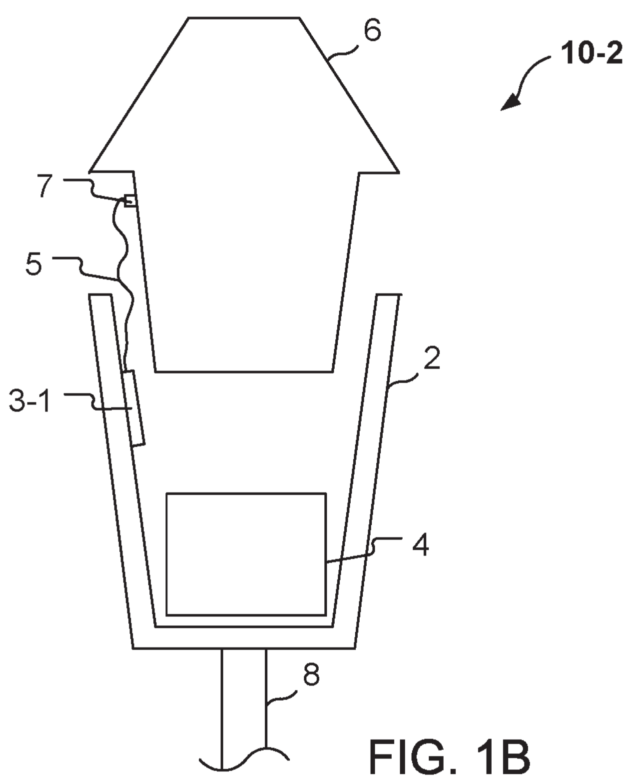


FIG. 1B

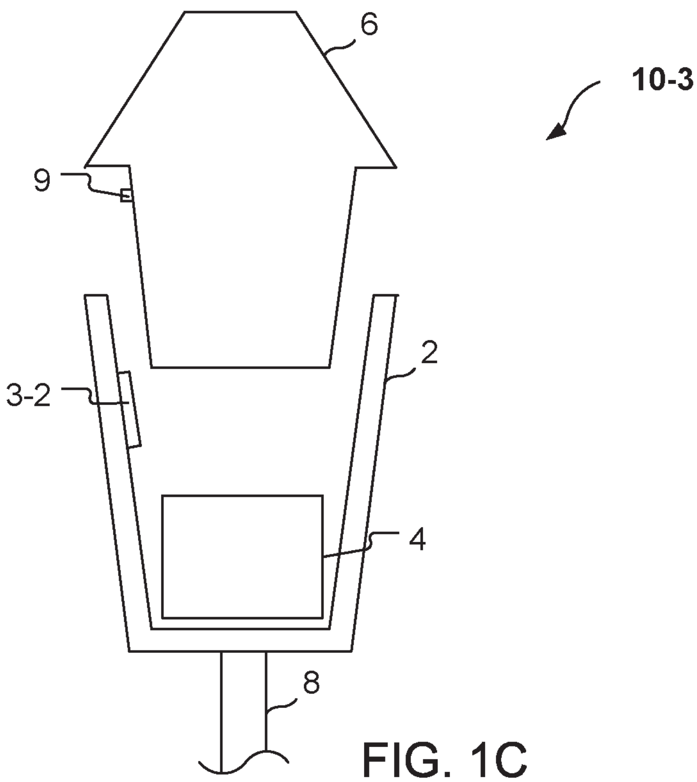
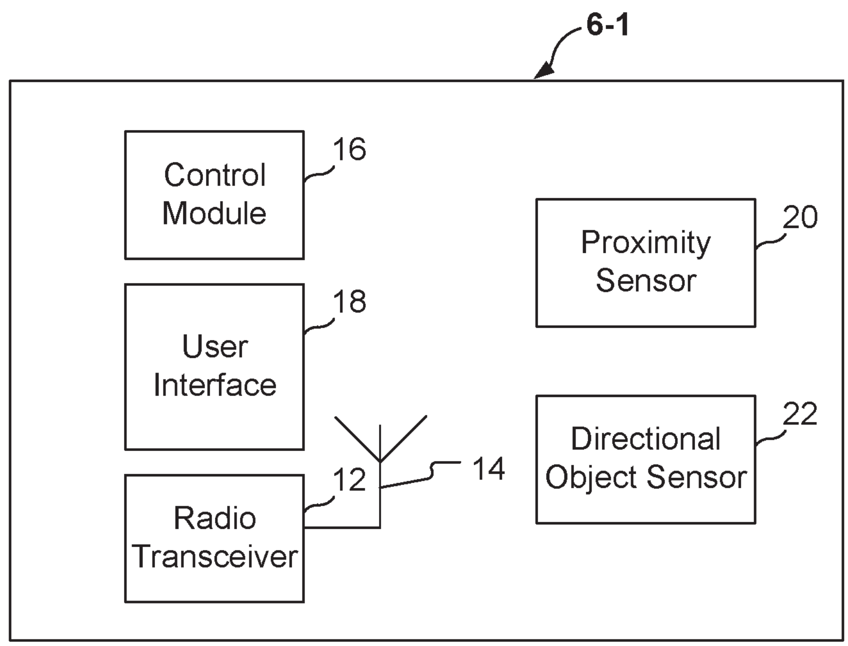


FIG. 1C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User Interface
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Radio Transceiver
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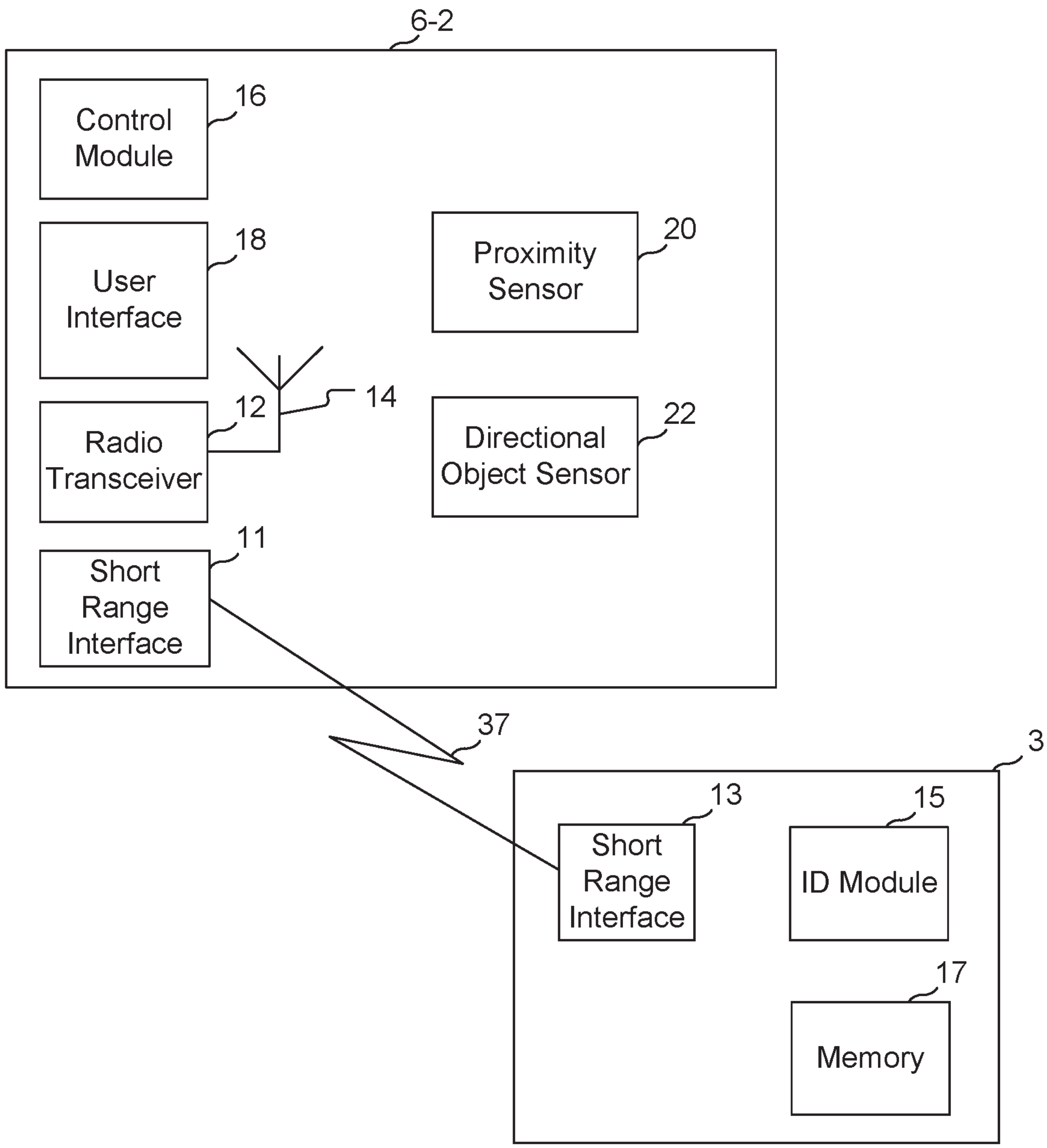
14
Proximity Sensor
20
Directional Object Sensor
22

FIG. 2A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User Interface
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Proximity Sensor
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Radio Transceiver
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Directional Object Sensor
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Short Range Interface
13
ID Module
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Memory
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FIG. 2B

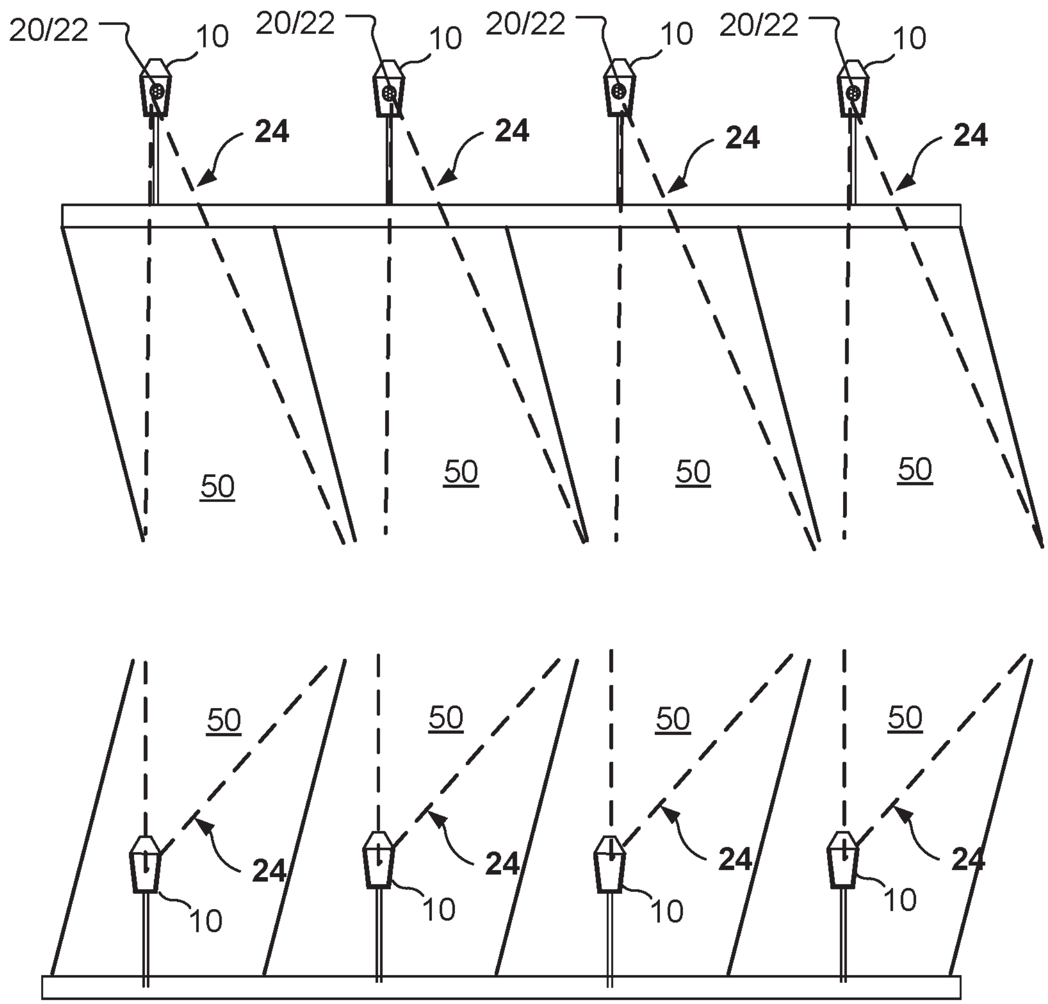
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FIG. 3

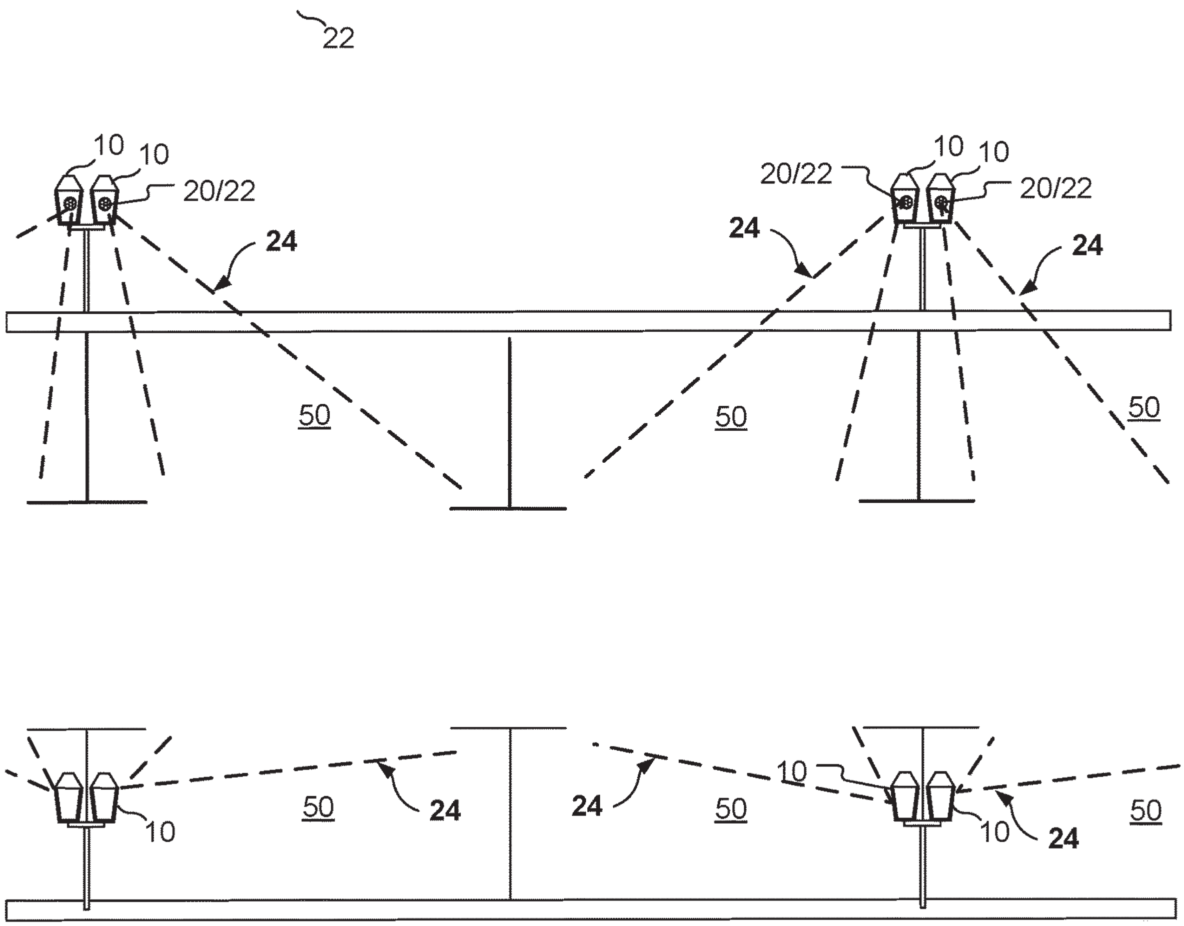
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FIG. 4

LOW-POWER VEHICLE DETECTION

RELATED APPLICATIONS

This application is a continuation of U.S. application Ser. No. 17/812,206, filed Jul. 13, 2022, now issued as U.S. Pat. No. 11,688,277 on Jun. 27, 2023, which is a continuation of U.S. application Ser. No. 16/913,246, filed on Jun. 26, 2020, now issued as U.S. Pat. No. 11,423,776 on Aug. 23, 2022, which is a continuation of U.S. application Ser. No. 16/383,203, filed on Apr. 12, 2019, now issued as U.S. Pat. No. 10,741,064 on Aug. 11, 2020, which is a continuation of U.S. application Ser. No. 15/633,290, filed on Jun. 26, 2017, now issued as U.S. Pat. No. 10,297,150 on May 21, 2019, which is a continuation of U.S. application Ser. No. 14/811,641, filed on Jul. 28, 2015, now issued as U.S. Pat. No. 9,728,085 on Aug. 8, 2017, which is a continuation of U.S. application Ser. No. 13/558,242, filed on Jul. 25, 2012, now issued as U.S. Pat. No. 9,127,964 on Sep. 8, 2015, which claims priority to U.S. Provisional Patent Application No. 61/511,484, filed Jul. 25, 2011, each of which are hereby incorporated by reference in their entireties and for all purposes.

BACKGROUND

Solar and/or battery powered parking systems such as single-space or multi-space meters for vehicles can employ parking meters with vehicle detection systems that detect the presence of a vehicle in a parking space. Time paid for parking in the space can then be dependent on the space being occupied by a vehicle. One technique for detecting the presence of a vehicle is to use a magnetometer located in the parking space. A magnetometer can be advantageous because it has relatively low power requirements, and often can be suitably powered by a battery. A magnetometer must be located close to the vehicle that will occupy the parking space, for accurate detection without false indications. Placement of a magnetometer in a parking space typically requires coring of the surface asphalt or concrete (i.e., drilling a cylindrical opening or shaft) for embedding the magnetometer in the adjacent street or sidewalk area. This can be a very labor intensive and relatively expensive proposition.

Alternatively, a magnetometer could be included in a parking meter of the parking space, which would avoid the surface coring and embedding of the magnetometer. This placement will usually decrease the accuracy of detection, because magnetometers possess no directional detection capability. Because of the directional deficiency, a magnetometer installed in a meter potentially could not distinguish between a vehicle parked in the space associated with the parking meter and a vehicle parked in an adjacent parking space, or could not distinguish between a vehicle parked in the space and a vehicle stopped in the street.

Other vehicle detection systems have employed ultrasonic or infrared systems internal to a parking meter. Such systems send out a known ultrasonic or infrared signal and evaluate vehicle presence based on partial reflection of the signal, or lack thereof. The signal can be modulated for improved accuracy of detection. Because parking meters, especially single-space parking meters, usually have a limited power budget, these ultrasonic and infrared systems are designed to be operated at relatively low power levels. Unfortunately, low-power ultrasonic and infrared systems are often prone to signal interference, due to pedestrian traffic, rain, snow, wind, and the like, and can have very narrow angles of detection. Accuracy of detection can be improved by increased signal power. Moreover, ultrasonic and infrared systems typically require a relatively large percentage of the transmitted signal to be reflected back for detecting the presence of a vehicle. Receiving a reflected signal that constitutes a large percentage of the transmitted signal can be problematic, given weather conditions and pedestrian traffic, and therefore ultrasonic and infrared systems can be inherently unreliable as a means for detecting the presence of a vehicle in a parking space.

Other vehicle detection systems that potentially could be more accurate than low-power magnetometers, ultrasonic systems, and infrared systems, include cameras, passive infrared systems (such as used in automatic door openers), active infrared detection, and radar. These other systems, while possibly providing very accurate detection of a vehicle in a parking space, typically use more power than can be provided by a battery, solar cell, or other low-power system of a battery and/or solar powered parking meter such as the single space meter described below. For example, radar can be very difficult to utilize because of power management issues, and often provides relatively unpredictable results.

It should be apparent that accurate vehicle detection systems either require extensive installation and/or maintenance costs, as with embedded magnetometer systems, or are very inaccurate when placed a distance away from the object to be detected, or use too much power for a single-space parking meter in order to be suitable. In addition, a directional sensor that is placed in the space to be monitored or external to a meter pole, may become compromised by dirt or debris, or may fall victim to tampering. What is needed is a more reliable, low power vehicle detection system for use in a solar and/or battery powered parking meter. The present invention satisfies this need.

SUMMARY

A parking meter detects an object in proximity, based on a change in a proximity measurement at the meter, activates a directional sensor in response to detecting the object, receives sensor data at a meter processor from the directional sensor, wherein the received sensor data indicates a predetermined direction to the detected object relative to the meter. The parking meter determines a presence of the object, or lack thereof, in the predetermined direction based on the sensor data, and upon a positive determination of the presence of the object, stores an indication of the presence of the object along with a time of the positive determination.

Further areas of applicability of the present disclosure will become apparent from the detailed description provided hereinafter. It should be understood that the detailed description and specific examples, while indicating various embodiments, are intended for purposes of illustration only and are not intended to limit the scope of the disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is now described, by way of a non-limiting example, with reference to the accompanying drawings, where like reference numerals refer to like objects, and in which:

FIGS. **1**A, **1**B, and **1**C are schematic illustrations of embodiments of single space parking meters.

FIG. **2**A shows a functional block diagram of a removable meter unit used in the parking meter of FIG. **1**A.

FIG. **2**B shows a functional block diagram of a removable meter unit and a tag device used in the parking meters of FIGS. **1**B and **1**C.

FIG. **3** shows an example of a local group of parking meters that employ a low power vehicle detection system in accordance with the disclosure.

FIG. **4** shows another example of a local group of parking meters that employ a low power vehicle detection system in accordance with the disclosure.

DETAILED DESCRIPTION

A parking meter for a parking space associated with the parking meter utilizes a proximity sensor to detect an object in proximity to the parking space and in response activates a directional sensor to detect the presence and direction of the object, such as a motor vehicle. The proximity sensor is a low-power sensor that can detect an object in proximity to the sensor, but generally has insufficient sensitivity and precision to identify the presence and direction of the object. For example, a low-power proximity sensor comprising a magnetometer can detect if a metallic object is in proximity to the magnetometer, but is generally incapable of detecting the direction in which the metallic object is located in relation to the magnetometer. The directional sensor typically draws more power than the proximity sensor and can comprise a sensor such as, but not limited to, an infrared, passive infrared, radar, or optical sensor, which is capable of determining the presence of an object in a specific direction relative to the higher-powered directional sensor. Such directional sensors typically require greater power for operation than can be supplied continuously or periodically by a typical power-limited device such as a single space parking meter. In accordance with the disclosure, the low-power proximity sensor can comprise a magnetometer, which is used as a trigger to activate the directional sensor to receive sensor data. The directional sensor data is analyzed to determine whether or not an object detected by the low-power sensor is located in a specific location associated with the directional sensor. This construction permits the use of a relatively higher power directional sensor having greater accuracy, such that the directional sensor can be activated only when needed, as indicated by the low-power sensor. This eliminates the need for providing continuous or periodic power to the higher power directional sensor.

In another aspect, after the directional sensor has verified the presence of an object of interest, the magnetic signature captured by the low-power sensor magnetometer can be inverted and used to determine the departure of the object of interest from the parking space. The departure indication can be used to reset any time remaining on the parking meter to zero or to some other desired amount of remaining time

In FIG. **1**A, an embodiment of a single space parking meter in accordance with this disclosure is designated generally by the reference numeral **10**-**1**. The parking meter **10**-**1** includes a location housing **2**, a cash collection box **4**, and a meter unit **6**. The location housing **2** is fixedly attached to a pole **8** associated with a parking space at a geographic location, with the cash collection box **4** and the meter unit **6** being received in the location housing. The meter unit **6** is a removable meter unit that can be replaced independently of other components of the meter **10**-**1** such as the housing **2** and cash collection box **4**. The cash collection box **4** is also removable and can also be replaced independently of the other meter components.

In FIG. **1**B, another embodiment of a single space parking meter is designated generally by the reference numeral **10**-**2**. The parking meter **10**-**2** includes the location housing **2**, the cash collection box **4**, the meter unit **6**, and an auxiliary device **3**-**1** in the form of a tag. The cash collection box **4**, the meter unit **6**, and the tag **3**-**1** are received within the housing **2**. The housing **2** is fixedly attached to the pole **8**. The tag **3**-**1** is permanently attached to an inner surface of the housing **2**. Attachment to an inner surface shields the tag from the outside environment and helps prevent damage and vandalism to the tag. The cash collection box **4** and meter unit **6** are removable and replaceable. In the example shown in FIG. **1**B, the tag **3**-**1** is connectable to the meter unit **6** by means of a length of wire **5** and a plug-in connector **7** at the meter unit, and can be powered by the meter unit (e.g., by a battery, solar cell, or other power source associated with the meter unit). The tag **3**-**1** is useful for associating the collection box **4** and meter unit **6** with the location.

Referring to FIG. **1**C, another embodiment of a single space parking meter is designated generally by the reference numeral **10**-**3**. The parking meter **10**-**3** is similar to the parking meter **10**-**2** of FIG. **1**B except that the parking meter **10**-**3** includes a wireless tag **3**-**2** and the meter unit **6**-**2** includes a wireless transceiver **9**. The wireless tag **3**-**2** communicates wirelessly with the meter unit and can be, for example, an RFID tag, a smart card, an ID token, or the like. The wireless transceiver **9** receives information from the tag **3**-**2** and, for example, can be a radio transceiver that uses passive RFID technology, Wi-Fi, Bluetooth, WiMAX, or other short range wireless radio technology, in accordance with the wireless communication channel used by the tag.

The wireless transceiver **9** of the parking meter **10**-**3** may be an infrared (IR) transceiver that emits an infrared beam for data communication. In that case, the transceiver **9** is aligned with the tag **3**-**2** such that the infrared beam of the transceiver is properly targeted at the tag **3**-**2**.

In one embodiment, the wired tag **3**-**1** or the wireless tag **3**-**2** is used to monitor the content of the cash collection box **4**. Each tag **3** has a unique identifier that identifies the parking meter **10** with which it is used, and that is associated with a unique physical location where the parking meter is fixedly located, e.g., the location of the pole **8** and the location housing **2**. Each tag **3** has a unique ID which is transmitted to the central management system. The ID is logically connected in the management system's database to that meter pole **8** and location specific settings. Therefore, the removable parking meter unit **6** may receive the correct hours of operation, rate tables, and other location-specific data related to that meter pole **8** associated with a specific parking space.

The embodiment of the location housing **2** in FIGS. **1**A, **1**B, and **1**C is a single or dual space type of housing that is affixed to the pole **8** and is configured to mate with a removable meter unit **6**. In other embodiments, however, the location housing **2** can be a cabinet or other enclosed space that is configured to mate with one or more removable meter units, where the removable meter units are configured to be mated in compartments or sockets of the cabinet, such that each of the compartments is associated with a physical location that is not necessarily at the same location as the cabinet or the compartment. In other embodiments, the location housing can be another type of receptacle fixedly placed and associated with a physical location.

FIG. **2**A is a functional block diagram of a removable meter unit that can be used in the meter **10**-**1** of FIG. **1**A and is designated generally by reference numeral **6**-**1**. The removable meter unit **6**-**1** includes a radio transceiver **12**, an antenna **14**, a control module **16**, a user interface **18** through which payment can be received, a proximity sensor **20**, and a directional object sensor **22**. The proximity sensor **20** is a low-power, non-directional, omnidirectional or multi-directional sensor such as a magnetometer, an optical sensor, a pressure sensor, an ultrasonic sensor, or the like, comprising a low-power sensor. As indicated above, the parking meter **10** is self-powered and, as described more fully below, uses the proximity sensor **20** and the directional object sensor **22** to detect a presence of a vehicle in a parking spot associated with the parking meter **10-1** and operates under control of the control module **16**. Optionally, the directional object sensor **22** may be located outside the meter unit **6-1** and wirelessly connected to the meter unit **6-1** using a low power radio link. For example, a directional object sensor may be placed on the pole **8** or on another pole or similar object.

The control module **16** includes one or more processors such as application specific integrated circuits (ASICs), digital signal processors (DSPs), digital signal processing devices (DSPDs), programmable logic devices (PLDs), field programmable gate arrays (FPGAs), processors, controllers, micro-controllers, microprocessors, other electronic units designed to perform the functions described herein, and/or a combination thereof. The control module **16** also includes one or more storage mediums. A storage medium can include one or more memories for storing data, including read only memory (ROM), random access memory (RAM), magnetic RAM, core memory, magnetic disk storage mediums, optical storage mediums, flash memory devices and/or other machine readable mediums for storing information.

The user interface **18** provides a means for a location user to interact with the meter unit **6-1** and can include, for example, a display, one or more lights, and a keypad. The user interface **18** can provide a payment interface including a currency receiver for receiving coins and/or bills from a user in payment for using the parking location, as well as a reader for processing credit cards, debit cards, payment tokens, or proximity cards like Paywave™ and Paypass™ or NFC solutions like Google Wallet™ and the like. The control module **16** is coupled to the user payment interface and is configured to receive payment information regarding the amount of a payment and/or card or token information received at the payment interface. The control module **16** communicates the payment information from the user interface **18**, via the radio transceiver **12**, with the remote data manager. The one or more lights of the user interface **18** can be used as an indicator as to the payment status or, as discussed further below, can be used to produce an indication that a parking space that is associated with the location of the meter **10** is occupied.

In this example, the low-power sensor comprising the proximity sensor **20**, and the directional sensor **22**, are located within or attached to the removable meter unit **6** of the parking meter **10-1**. Alternatively, the proximity sensor **20** and the directional sensor **22** could be located on another portion of the meter **10-1** and/or could be located on the pole **8**. The proximity sensor **20** is coupled to the control module **16** and communicates a trigger signal to the control module **16** when a proximity measurement exceeds a threshold level. Upon receiving the trigger signal from the proximity sensor **20** the control module **16** wakes up the directional object sensor **22** such that the directional object sensor **22** can verify if an object is not only located near the parking meter **10-1**, but is located within a parking space associated with the parking meter **10-1**. The directional object sensor **22** can be an optical sensor (e.g., a digital camera), a passive infrared sensor, a radar sensor, an active infrared sensor, or the like.

FIG. **2**B shows functional block diagrams of an exemplary removable meter unit **6-2** and a tag **3** that can be used in meters such as the meters **10-2** and **10-3** of FIGS. **1**B and **1**C. The meter unit **6-2** includes similar components to the meter unit **6-1** in FIG. **2**A, including the radio transceiver **12**, the antenna **14**, the control module **15**, the user interface **18**, the proximity sensor **20** and the directional object sensor **22**. In addition, the meter unit **6-2** also includes a short range interface **11** by means of which it communicates with the tag **3**. The tag **3** has a short range interface **13**, an ID module **15**, and an optional memory module **17** for storing information regarding operating parameters including a payment collection history and/or configuration settings. The ID module **15** stores a unique identifier, e.g., a serial number, that is associated with the tag **3**.

The meter unit **6-2** is linked to the tag **3** for data communications by a link **37**. In the case where the tag **3** is a wired tag **3-1**, the link **37** is the wire **5** (see FIG. **1**B). In the case where the tag **3** is a wireless tag **3-2**, the link **37** can be a radio link or an optical link (FIG. **2**B). In the case of a wireless tag **3-2**, the short range interfaces **11** and **13** can be any type of near-field communication (NFC) devices such as, for example, RFID devices, Bluetooth devices, Wi-Fi devices, IR devices, and the like.

The proximity sensor **20** and the directional sensor **22** operate similarly in the meter unit **6-2** as in the meter unit **6-1** described above. In an alternative arrangement, not shown, the proximity sensor **20** and/or the directional object sensor **22** can be co-located with the housing **2**, the tag **3**, the cash box **4** or the pole **8**. In these arrangements, the proximity sensor **20** and/or the directional object sensor **22** can be coupled to the short range interface **13** of the tag **3** or to another short range interface so as to communicate detection signals to the control module **16**.

In one embodiment, the control module **16** communicates the payment information, via the link **37**, to the short range interface **13** of the tag **3**. The short range interface **13** then updates the optional memory module **17** based on the received payment information. The memory module **17** can add the amount of currency indicated to have been received by the received payment information to the stored amount. This is useful when the meter unit **6** is swapped for maintenance reasons as thereby coin counts can be transferred to the replacement meter unit and the coin audit reliability is maintained. In addition, the memory module **17** can also receive and store transaction-time information including the date and time of day that the payment was received. In one aspect of this embodiment, the control module **16** communicates time of day information of when a vehicle enters and leaves a parking spot, as detected by the proximity sensor **20** and the directional object sensor **22**, to the tag **3**.

FIG. **3** shows an example configuration of a group of parking meters **10** equipped with the proximity sensor **20** and the directional object sensor **22** and positioned near single-space parking spaces **50**. The parking spaces **50** in this example are diagonal pull-in spaces, as indicated by the solid lines angled from the lateral lines indicating a curb or street edge. The directional object sensor **22** in each of the respective meters **10** is positioned and calibrated such than an object such as a vehicle that moves into a position in proximity to the meter will enter a space within a directional cone **24** indicated by dashed lines. The directional cone **24** is a space that is projected outwardly from the associated parking meter **10** and towards the specific parking space **50** associated with the parking meter **10** and with which the directional object sensor **22** is associated. An object, such as a vehicle, that enters the area of the directional cone **24** will be detected, first by the low-power proximity sensor **20**, which detects the presence of the object of interest, and which then triggers the higher power directional object sensor **22**. The directional object sensor **22** receives power sufficient to make a determination for confirming the presence of a vehicle in the parking space **50**.

FIG. **4** shows another example configuration of a group of parking meters **10** equipped with the proximity sensor **20** and the directional object senor **22**, where the meters **10** are positioned near parallel parking spaces **50**. That is, the parallel parking spaces are oriented parallel to the lateral curb or road edge depicted in FIG. **4**. The directional cones **24** can be calibrated digitally by setting directional gains to enhance signals within predetermined areas for the detection of objects of interest, such as vehicles attempting to park. Alternatively, the directional object sensors **22** could be positioned and/or shielded to produce the desired directional cone **24**.

A process for operating a parking meter **10** equipped with a low-power sensor **20** such as a proximity sensor and a directional sensor **22** can comprise the following operations (not necessarily in the order listed):

1. detecting an object in proximity to a parking meter with a low-power sensor coupled to the parking meter; if, for example, the low-power sensor is a magnetometer, then the object is detected based on a change in a magnetic field at the meter;
2. in response to the trigger event, activating a directional sensor;
3. receiving sensor data at the directional sensor from a predetermined direction relative to the meter;
4. determining a presence of an object, or lack thereof, in the predetermined direction based on the received sensor data; and
5. upon a determination of the presence of the object, storing an indication of the presence of the object along with a time of the determined presence.

A threshold change in the magnetic field that results in detection of the object can be determined empirically. A time threshold can also be used (if change in magnetic field lasts for more than a threshold time). The magnetic field threshold and the time threshold can vary on the configuration of the parking space and the orientation of the parking meter. The sensitivity and directional gains, which can be used to tune the aim of the directional sensor, can also be determined empirically. Adaptive algorithms could be used to fine-tune the time threshold, the proximity sensor detection levels and the directional gains associated with the directional sensor.

Determining the presence of the object based on the received sensor data can include determining a confidence measure and/or a margin of error measure. For example, if the directional sensor is an ultrasonic sensor, the ultrasonic sensor receives an echo representative of a size and distance of the object. A valid vehicle detect status maybe, for example, an echo from a large object at a distance between 3.0 feet and 9.0 feet. A large object at 5.0 feet would be in the middle of the expected parameters and would have a higher confidence or a smaller margin of error than a smaller object at, for example, 3.0 feet. Similarly visual detection could evaluate the size and position of the object against an expected vehicle size. The meter can vary subsequent actions depending on the confidence measure and/or the margin of error measure. For example, the meter may only report a parking violation if the vehicle presence detection is above an 80% confidence value.

In addition to detecting the object in proximity to the parking meter, the low-power proximity sensor could be used to detect when the object subsequently departs the proximity of the parking meter. For example, if the proximity sensor is a magnetometer, the control module could determine a change in magnitude of the magnetic field from a baseline value, where the baseline value is a value indicative of no object being in proximity to the parking meter. The magnetometer measurement can be a one, two, or three degrees-of-freedom (DOF) measurement that includes direction(s). Subsequent to the initial change in magnitude and direction of the magnetic field, the control module can detect an opposite change in magnitude and direction of the magnetic field and determine that the object has departed the proximity of the parking meter.

In embodiments that use a magnetometer, a baseline measurement can be determined as follows. A three DOF magnetometer returns a vector, (x, y, z), that represents the magnetic field around the meter. The baseline measurement represents an expected measurement vector (along x, y, z axes) when no vehicle is present in proximity to the meter. The baseline condition can be time-adapted to absorb a change in the environmental magnetic field or a shift in the measurement offset. Occasionally, the baseline measurement is not set or has drifted beyond a tracking window. In that case, it is beneficial to automatically determine a new baseline value without knowing when a vehicle is absent or present. The traditional way of doing this is to have a person visit the parking site and command the meter to determine a new baseline when no vehicle is present. This is time-consuming, especially in areas where there is a high occupancy rate and one must wait for a vehicle to depart.

An alternative way of determining a new baseline measurement when no vehicle is present is to have the control module of the meter receive the (x, y, z) measurements from the magnetometer after each step-change in readings. The (x, y, z) measurements are stored in a memory coupled to the control module. When sufficient measurements are captured over a minimum time period, the measurement data is analyzed to find a single cluster of readings. Because each vehicle has a different magnetic signature, the magnetic field measurement values obtained when one or more vehicles are present in proximity to the meter will be scattered substantially across the (x, y, z) space. The baseline measurements that correspond to no vehicles being present should generally be in a single cluster group in the (x, y, z) space. The center of the clustered measurements is determined and used as the new baseline measurement. That is, an object can be detected by comparing the proximity measurement to a baseline measurement, wherein the baseline measurement represents an expected proximity measurement when the object is not present, such that the object is deemed to be positively detected if the proximity measurement differs from the baseline measurement by more than a threshold value. The threshold value can be set depending on the environmental factors of the installation and types of vehicles to be detected.

The parking meter **10** described above includes a low-power proximity sensor **20** and a separate directional sensor **22**. An alternative parking meter could use a single sensor including a low power proximity sensor integrated with a directional sensor. The integrated sensor would operate in a low power mode with only the low-power proximity sensor active and, when the proximity sensor detects an object in proximity to the meter, the directional sensor would be activated to detect the presence of the object in a predetermined location relative to the meter. Yet another alternative parking meter could use a single sensor that operates in a low-power mode and in a high-power mode. In the low-power mode, the single sensor of this alternative would be able to detect an object in proximity to the meter, but would not be able to detect the location of the object relative to the meter (an omnidirectional mode). In the high power mode, which would be activated when the sensor in the low-power mode detects an object, the single sensor would be switched to the high-power mode in order to sense the location of the object relative to the meter (a directional mode).

We claim:

1. A low-power sensor apparatus for monitoring a parking space, the sensor apparatus comprising: a first sensor, a second sensor, a wireless transceiver, and a control module comprising one or more processors and coupled to the first sensor, the second sensor, and the wireless transceiver;

wherein the second sensor has a more focused detection area than the first sensor and draws more power during operation than the first sensor,

wherein the first sensor detects a change in a presence of an object in a parking space based on a change in a sensor measurement,

wherein the one or more processors of the control module determine a payment status of the parking space, identify a potential parking violation based at least on the change in the sensor measurement and the payment status, and activate the second sensor in response to the potential parking violation,

wherein the second sensor captures sensor data pertaining to the presence of the object in the parking space, and

wherein the one or more processors of the control module transmit, by the wireless transceiver, the sensor data to one or more of: a parking meter associated with the parking space, a remote data manager, and a handheld device.

2. The sensor apparatus of claim **1**, wherein the second sensor comprises one or more cameras.

3. The sensor apparatus of claim **2**, wherein the second sensor further comprises one or more of: an ultrasonic sensor, an optical sensor, a passive infrared sensor, an active infrared sensor, and a radar sensor.

4. The sensor apparatus of claim **1**, wherein the wireless transceiver utilizes a near field communication (NFC) protocol.

5. The sensor apparatus of claim **1**, wherein the wireless transceiver utilizes Bluetooth.

6. The sensor apparatus of claim **1**, wherein the first sensor is a non-directional, omnidirectional, or multi-directional sensor.

7. The sensor apparatus of claim **1**, wherein the first sensor comprises one or more of: a radio transceiver, a magnetometer, an optical sensor, and a pressure sensor.

8. The sensor apparatus of claim **1**, wherein the second sensor has a higher detection accuracy or precision than the first sensor.

9. The sensor apparatus of claim **1**, wherein the one or more processors of the control module determine a confidence level of the potential parking violation based on one or more of: the change in the sensor measurement, the payment status, and the captured sensor data.

10. The sensor apparatus of claim **9**, wherein the one or more processors of the control module, subsequent to determining the confidence level, vary an action of the parking meter based on the confidence level.

11. The sensor apparatus of claim **10**, wherein the action of the parking meter is to reset time remaining on the parking meter to zero or another amount.

12. The sensor apparatus of claim **1**, wherein the one or more processors of the control module, upon detecting the change in the presence of the object in the parking space, store an indication of the change in the presence of the object along with a time of the detection.

13. The sensor apparatus of claim **12**, wherein the indication comprises the sensor data.

14. The sensor apparatus of claim **1**, further comprising a power source coupled to the first sensor, the second sensor, the wireless transceiver, and the control module.

15. The sensor apparatus of claim **14**, wherein the power source comprises at least one solar cell and at least one battery.

16. The sensor apparatus of claim **1**, wherein the one or more processors comprises one or more application specific integrated circuits (ASICs), one or more digital signal processors (DSPs), one or more digital signal processing devices (DSPDs), one or more programmable logic devices (PLDs), one or more field programmable gate arrays (FPGAs), one or more controllers, one or more micro-controllers, one or more microprocessors, or a combination thereof.

17. The sensor apparatus of claim **1**, wherein the one or more processors comprises one or more memories for storing data.

18. The sensor apparatus of claim **17**, wherein the one or more memories for storing data comprises read only memory (ROM), random access memory (RAM), magnetic RAM, a magnetic storage medium, an optical storage medium, or flash memory.

19. A method of metering a parking space, the method comprising:

a) detecting a change in a presence of an object in a parking space based on a change in a sensor measurement by a first sensor;

b) determining a payment status of the parking space;

c) identifying a potential parking violation based at least on the change in the sensor measurement and the payment status;

d) activating a second sensor in response to the potential parking violation, the second sensor having a more focused detection area than the first sensor, the second sensor having a higher power draw during operation than the first sensor;

e) capturing sensor data by the second sensor pertaining to the presence of the object in the parking space; and

f) transmitting the sensor data wirelessly.

20. The method of claim **19**, wherein the second sensor comprises one or more cameras.

21. The method of claim **19**, wherein the transmitting utilizes a near field communication (NFC) protocol.

22. The method of claim **19**, wherein the transmitting utilizes Bluetooth.

23. The method of claim **19**, wherein the sensor data is transmitted to one or more of: a parking meter associated with the parking space, a remote data manager, or a handheld device.

24. The method of claim **19**, further comprising determining a confidence level of the potential parking violation based on one or more of: the change in the sensor measurement, the payment status, and the captured sensor data.

25. The method of claim **24**, further comprising resetting time associated with the parking space to zero or another amount based on the confidence level.

26. The method of claim **24**, further comprising updating the payment status of the parking space based on the confidence level.

27. The method of claim **19**, further comprising storing an indication of the change in the presence of the object along with a time of the detection.

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