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(54) **AUTOMATED ELECTRIC VEHICLE CHARGING SYSTEM AND METHOD**

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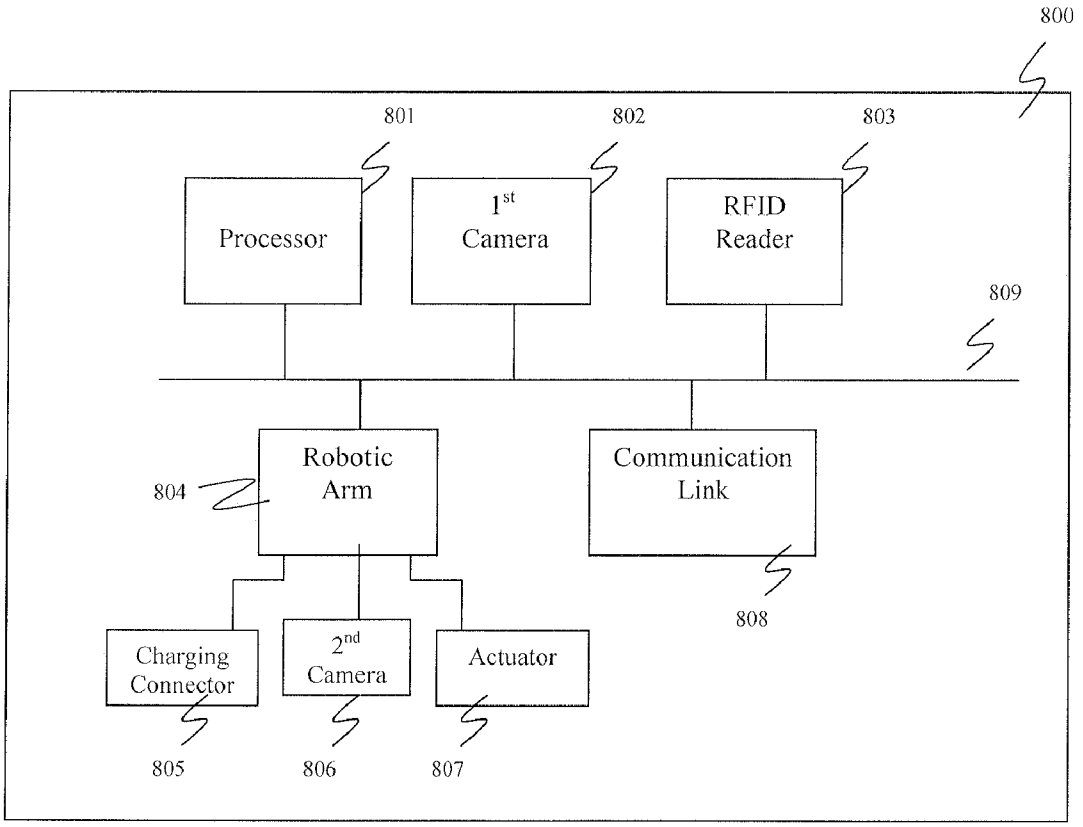
(57) **ABSTRACT**

A system and method for charging an electric vehicle includes identifying vehicle information corresponding to the electric vehicle based on an electronic image of the electric vehicle, retrieving from an electronically stored local database a location of a charging port on the electric vehicle based on the vehicle information, robotically moving a charging connector according to the retrieved location to engage the charging port of the electric vehicle, querying the local database to determine whether a current time corresponds to an energy efficient usage time based on energy efficient usage data received from a power grid, and initiating a charging process upon determining that the current time corresponds to the energy efficient usage time.



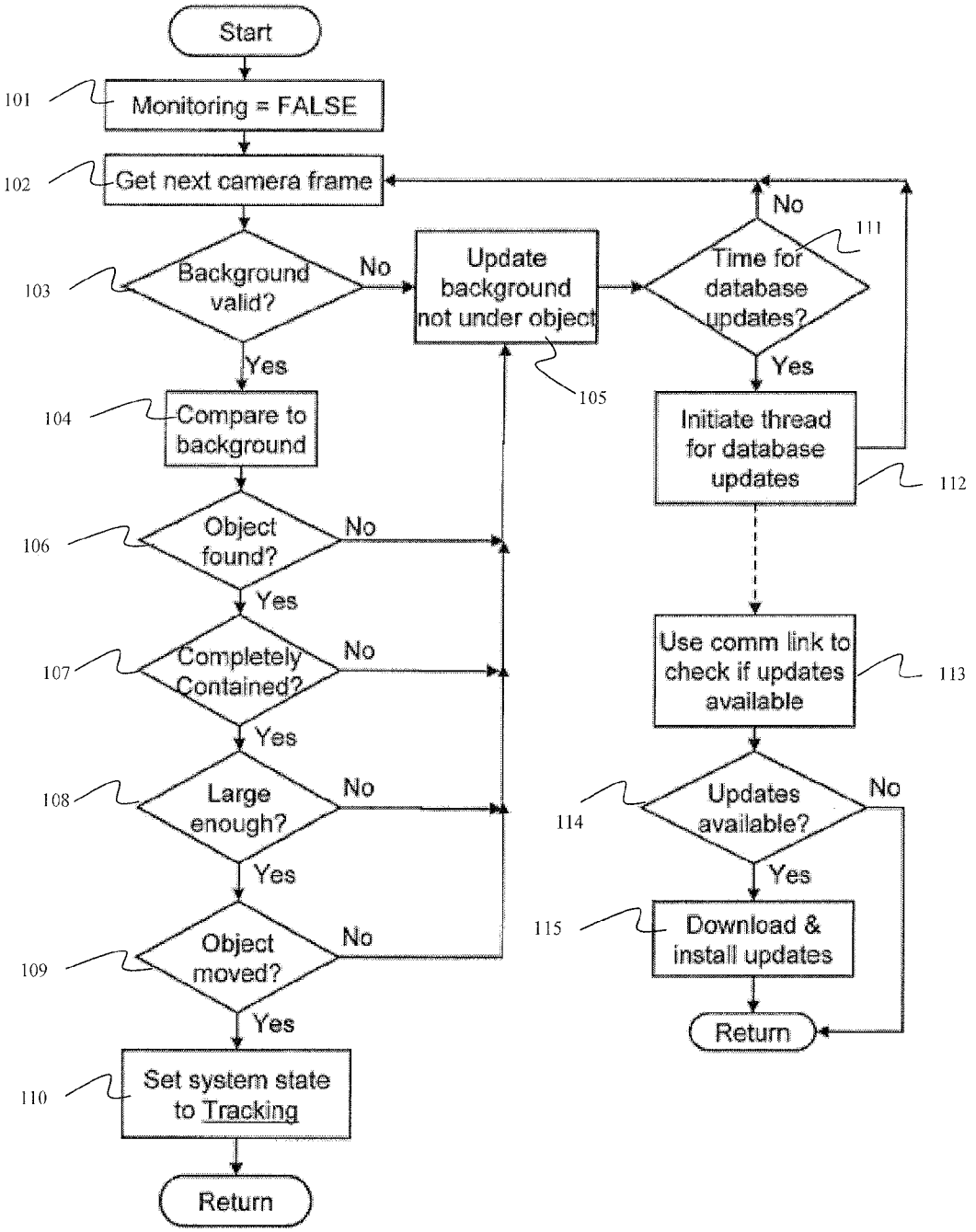

Start
101
Monitoring = FALSE
102
Get next camera frame
103
Background valid?
No
Update background not under object
105
Yes
104
Compare to background
106
Object found?
No
Yes
107
Completely Contained?
No
Yes
108
Large enough?
No
Yes
109
Object moved?
No
Yes
110
Set system state to Tracking
Return
111
Time for database updates?
No
Yes
Initiate thread for database updates
112
Use comm link to check if updates available
113
114
Updates available?
No
Yes
115
Download & install updates
Return

FIG. 1

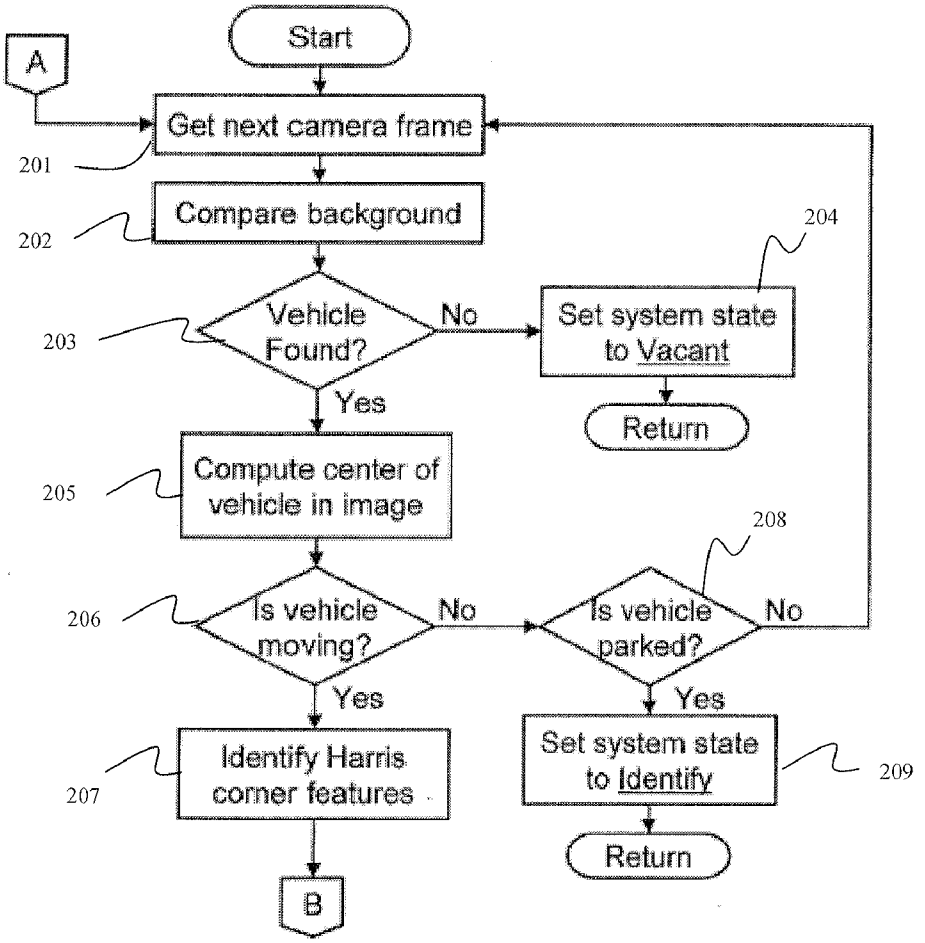

Start
A
Get next camera frame
201
Compare background
202
204
Vehicle Found?
203
No
Set system state to Vacant
Return
Yes
Compute center of vehicle in image
205
208
Is vehicle moving?
206
No
Is vehicle parked?
No
Yes
Yes
Identify Harris corner features
207
Set system state to Identify
209
Return
B

FIG. 2A

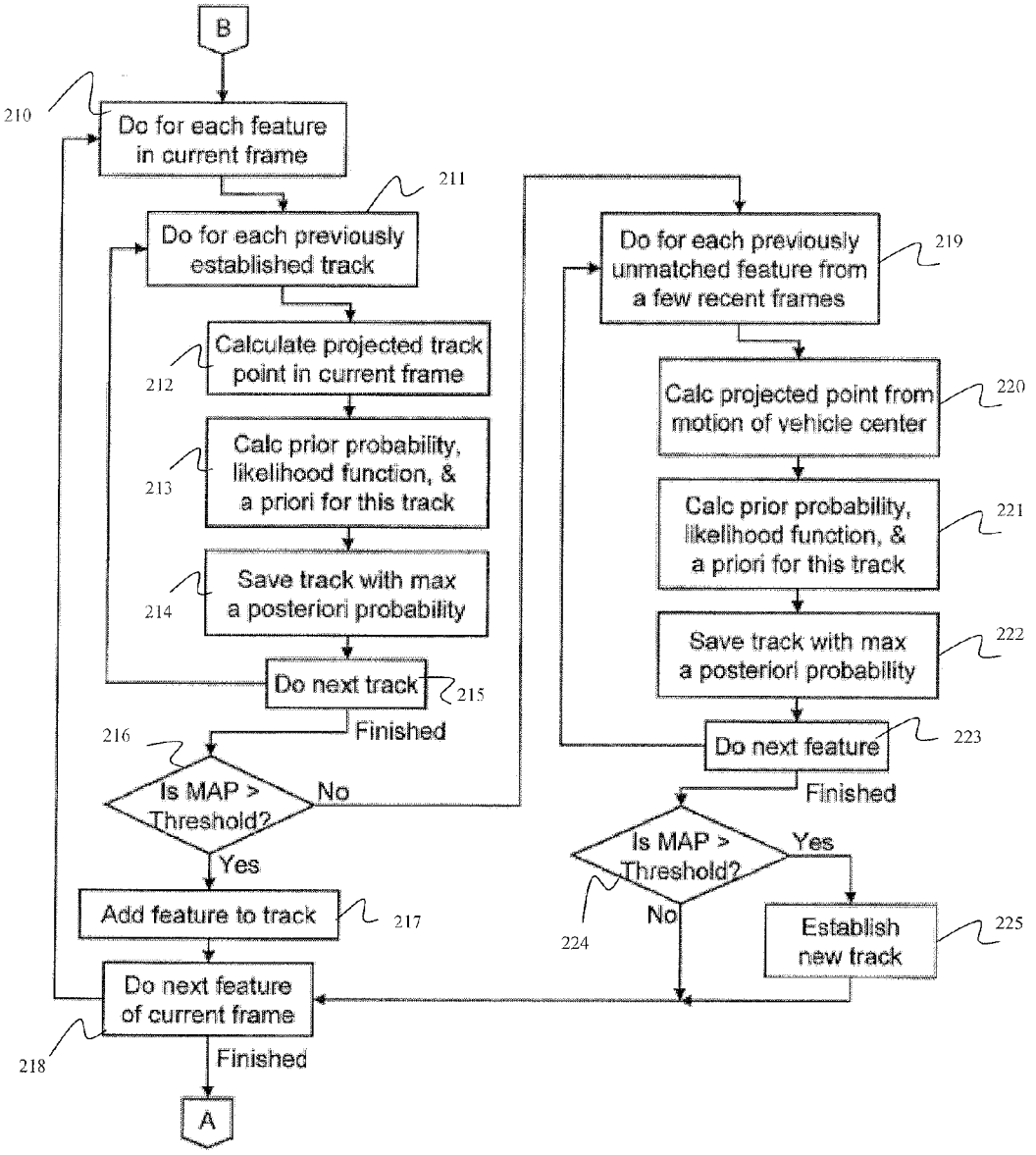

B
210
Do for each feature in current frame
211
Do for each previously established track
212
Calculate projected track point in current frame
213
Calc prior probability, likelihood function, & a priori for this track
214
Save track with max a posteriori probability
Do next track
215
Finished
216
Is MAP > Threshold?
No
Yes
Add feature to track
217
Do next feature of current frame
218
Finished
A
219
Do for each previously unmatched feature from a few recent frames
220
Calc projected point from motion of vehicle center
221
Calc prior probability, likelihood function, & a priori for this track
222
Save track with max a posteriori probability
Do next feature
223
Finished
Is MAP > Threshold?
Yes
224
No
Establish new track
225

FIG. 2B

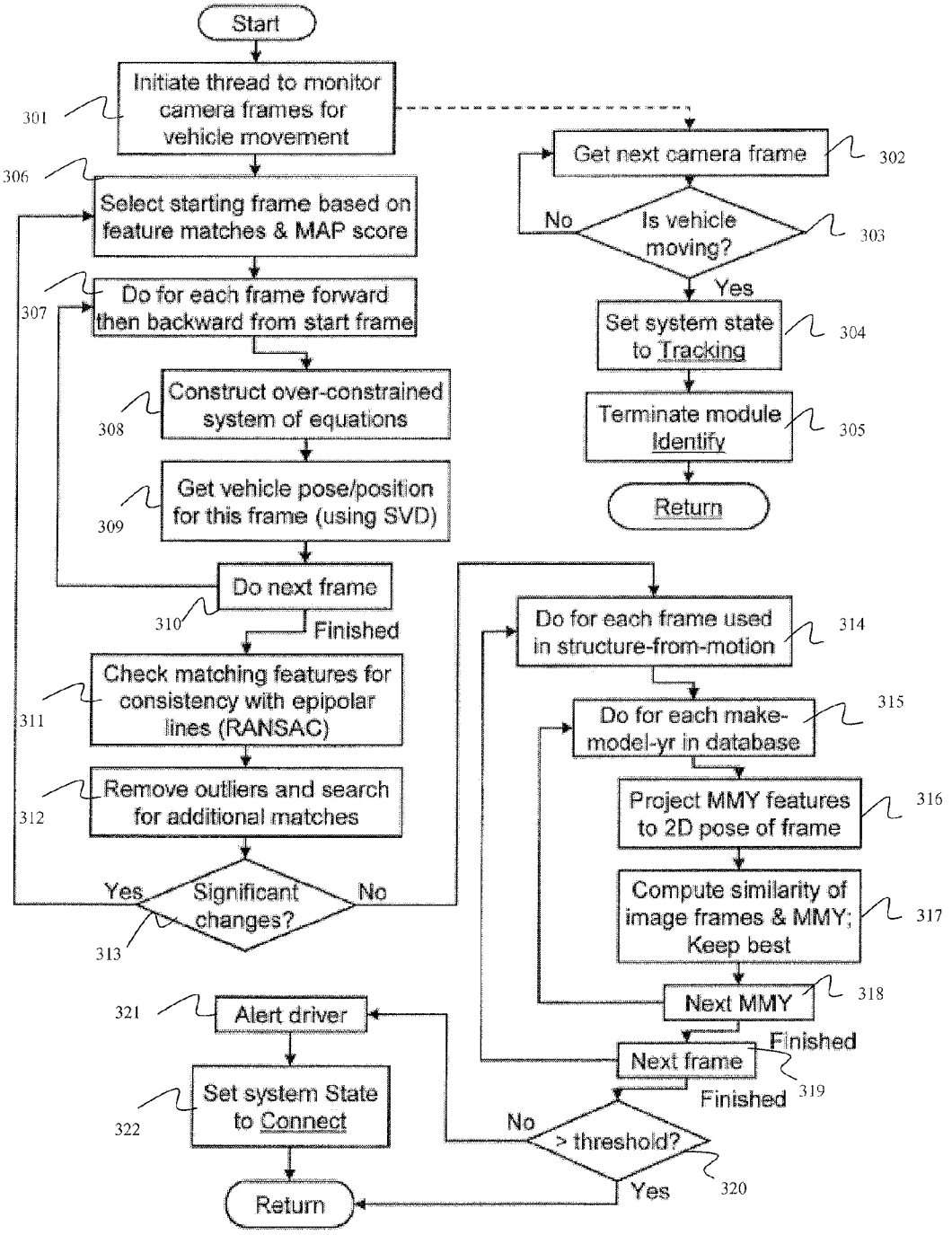

Start
Initiate thread to monitor camera frames for vehicle movement
301
Get next camera frame
302
No
Is vehicle moving?
303
Yes
Set system state to Tracking
304
Terminate module Identify
305
Return
306
Select starting frame based on feature matches & MAP score
307
Do for each frame forward then backward from start frame
308
Construct over-constrained system of equations
309
Get vehicle pose/position for this frame (using SVD)
310
Do next frame
Finished
311
Check matching features for consistency with epipolar lines (RANSAC)
312
Remove outliers and search for additional matches
313
Yes
Significant changes?
No
314
Do for each frame used in structure-from-motion
315
Do for each make-model-yr in database
316
Project MMY features to 2D pose of frame
317
Compute similarity of image frames & MMY; Keep best
318
Next MMY
Finished
319
Next frame
Finished
320
No
> threshold?
Yes
321
Alert driver
322
Set system State to Connect
Return

FIG. 3

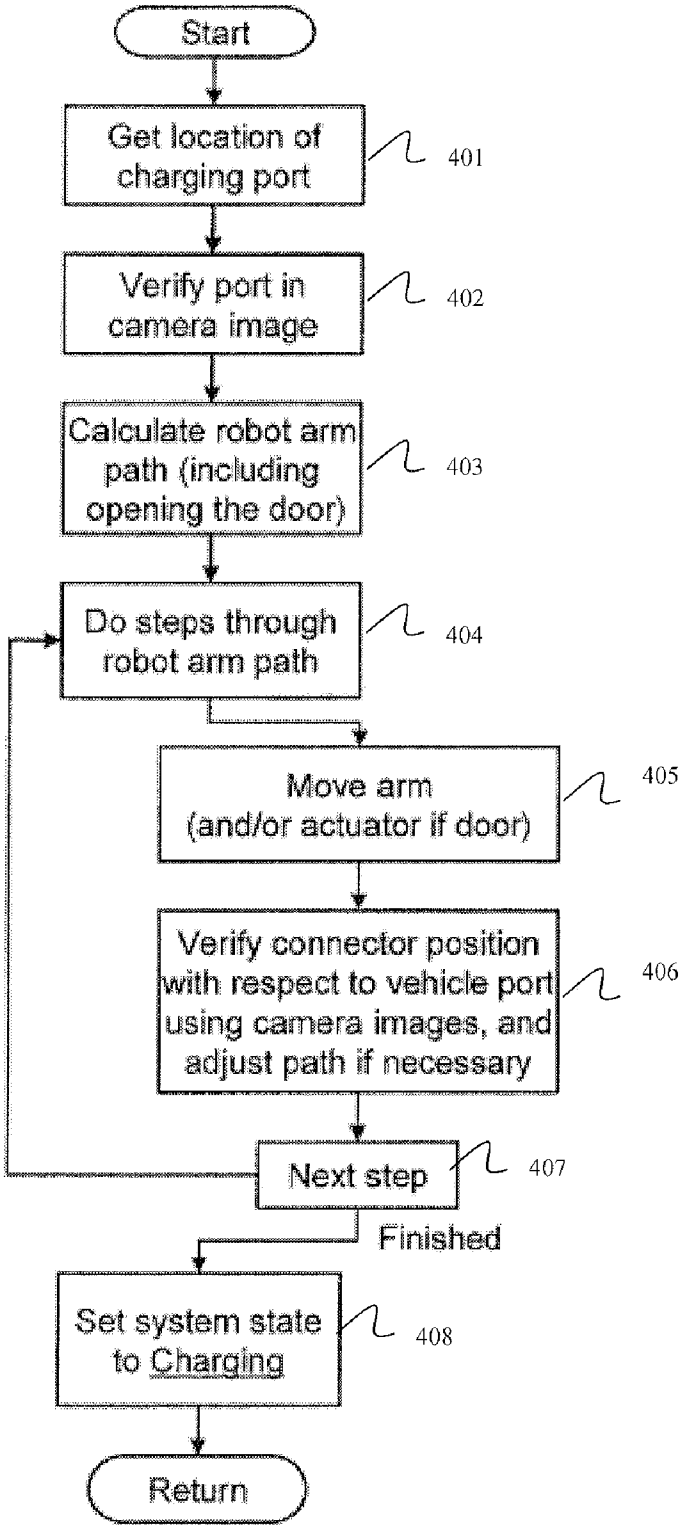

Start
Get location of charging port
401
Verify port in camera image
402
Calculate robot arm path (including opening the door)
403
Do steps through robot arm path
404
Move arm (and/or actuator if door)
405
Verify connector position with respect to vehicle port using camera images, and adjust path if necessary
406
Next step
407
Finished
Set system state to Charging
408
Return

FIG. 4

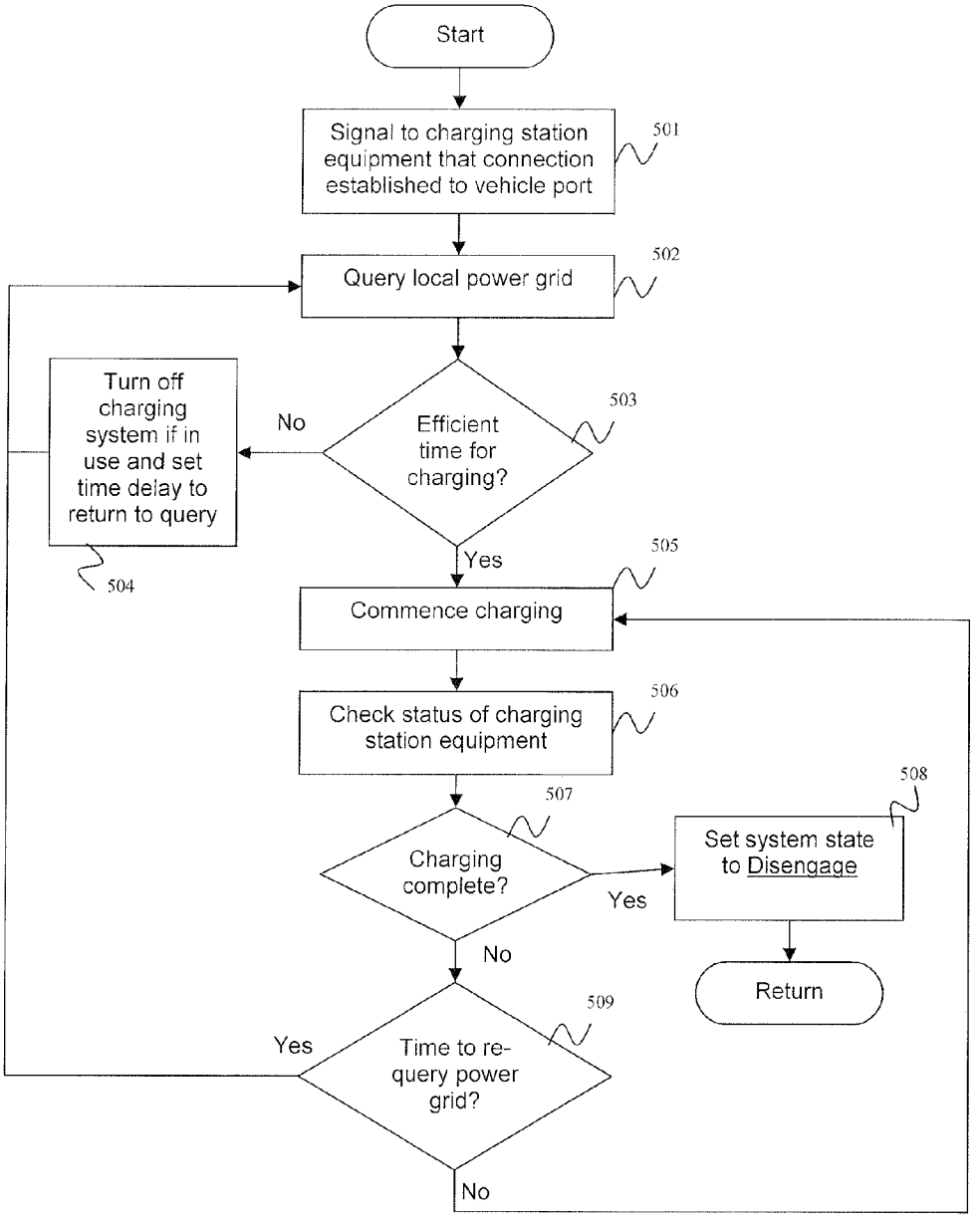

Start
Signal to charging station equipment that connection established to vehicle port
501
Query local power grid
502
Efficient time for charging?
503
No
Turn off charging system if in use and set time delay to return to query
504
Yes
Commence charging
505
Check status of charging station equipment
506
Charging complete?
507
Yes
Set system state to Disengage
508
Return
No
Time to re-query power grid?
509
Yes
No

FIG. 5

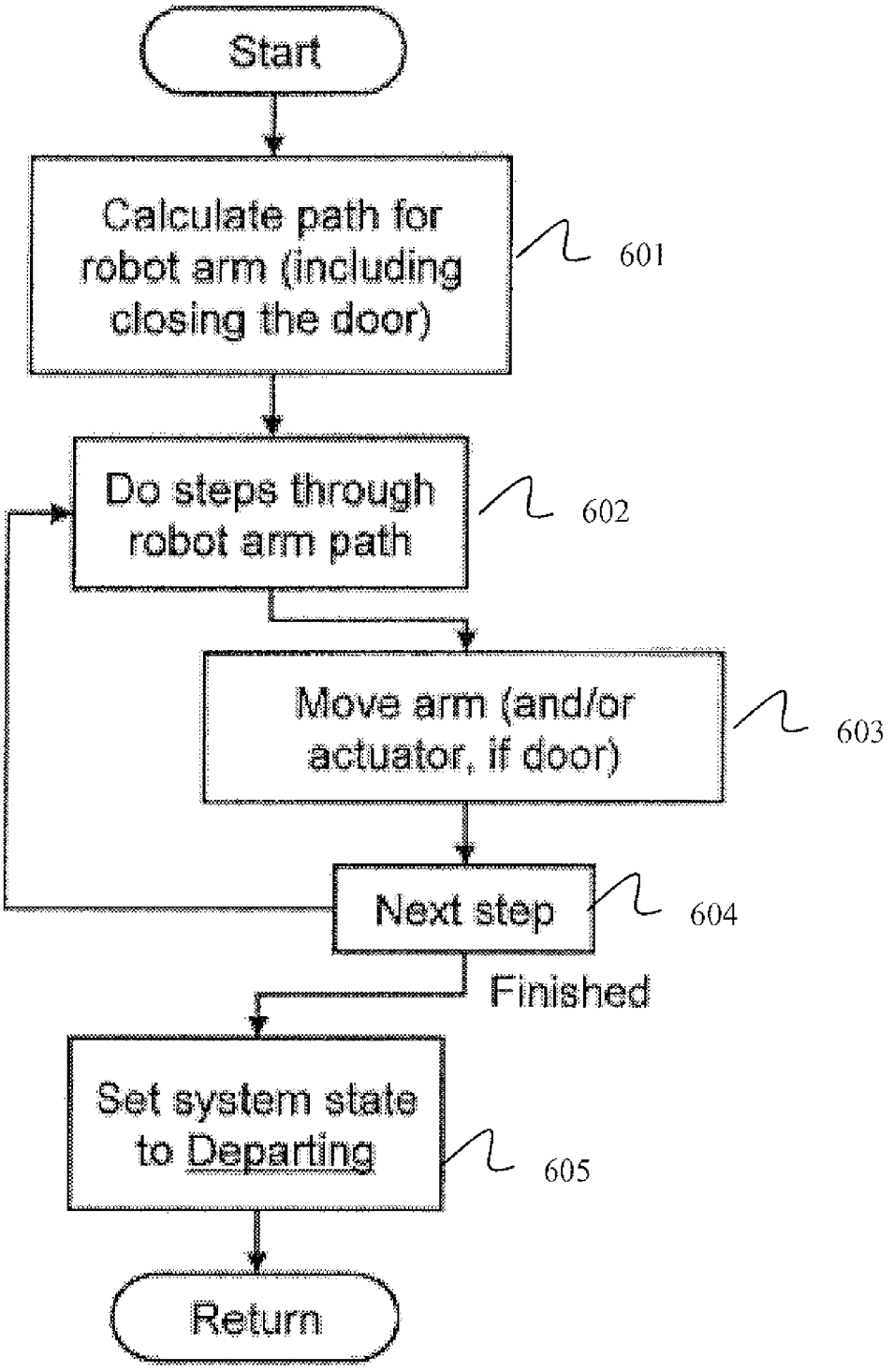

Start
Calculate path for robot arm (including closing the door)
601
Do steps through robot arm path
602
Move arm (and/or actuator, if door)
603
Next step
604
Finished
Set system state to Departing
605
Return

FIG. 6

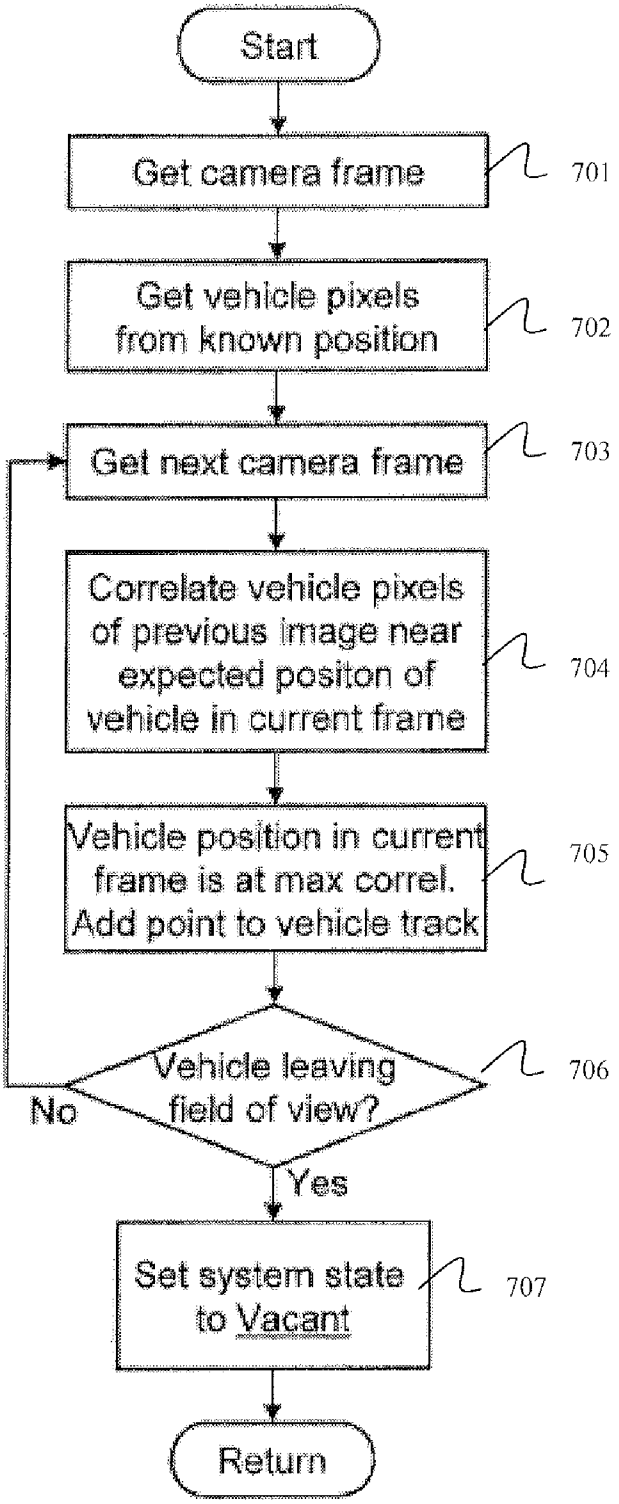

Start
Get camera frame
701
Get vehicle pixels from known position
702
Get next camera frame
703
Correlate vehicle pixels of previous image near expected positon of vehicle in current frame
704
Vehicle position in current frame is at max correl. Add point to vehicle track
705
Vehicle leaving field of view?
706
No
Yes
Set system state to Vacant
707
Return

FIG. 7

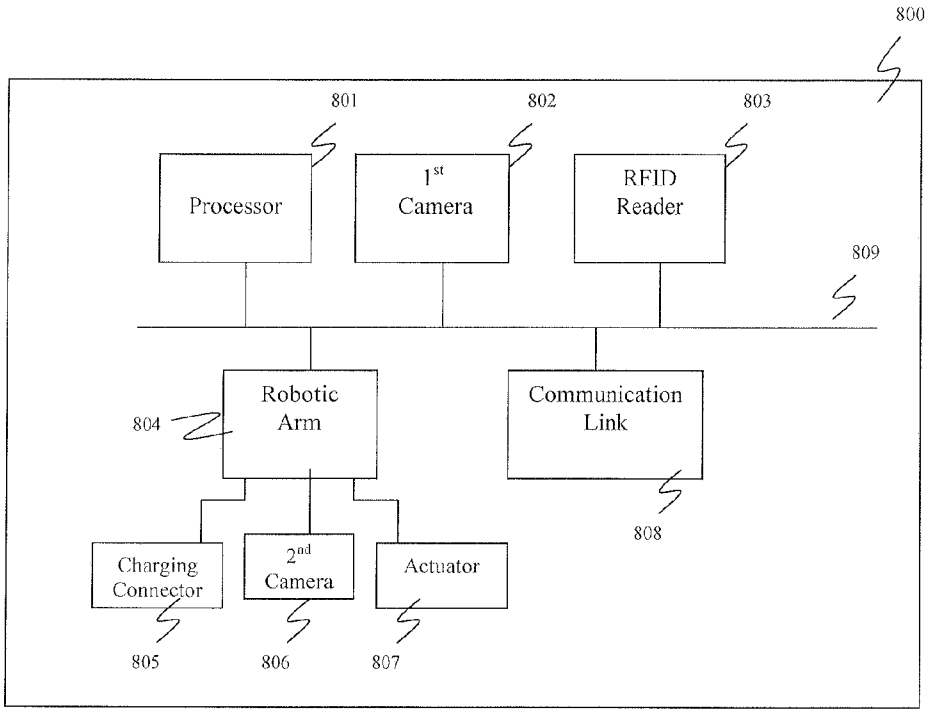

800
801
802
803
Processor
1st Camera
RFID Reader
809
804
Robotic Arm
Communication Link
808
Charging Connector
2nd Camera
Actuator
805
806
807

FIG. 8

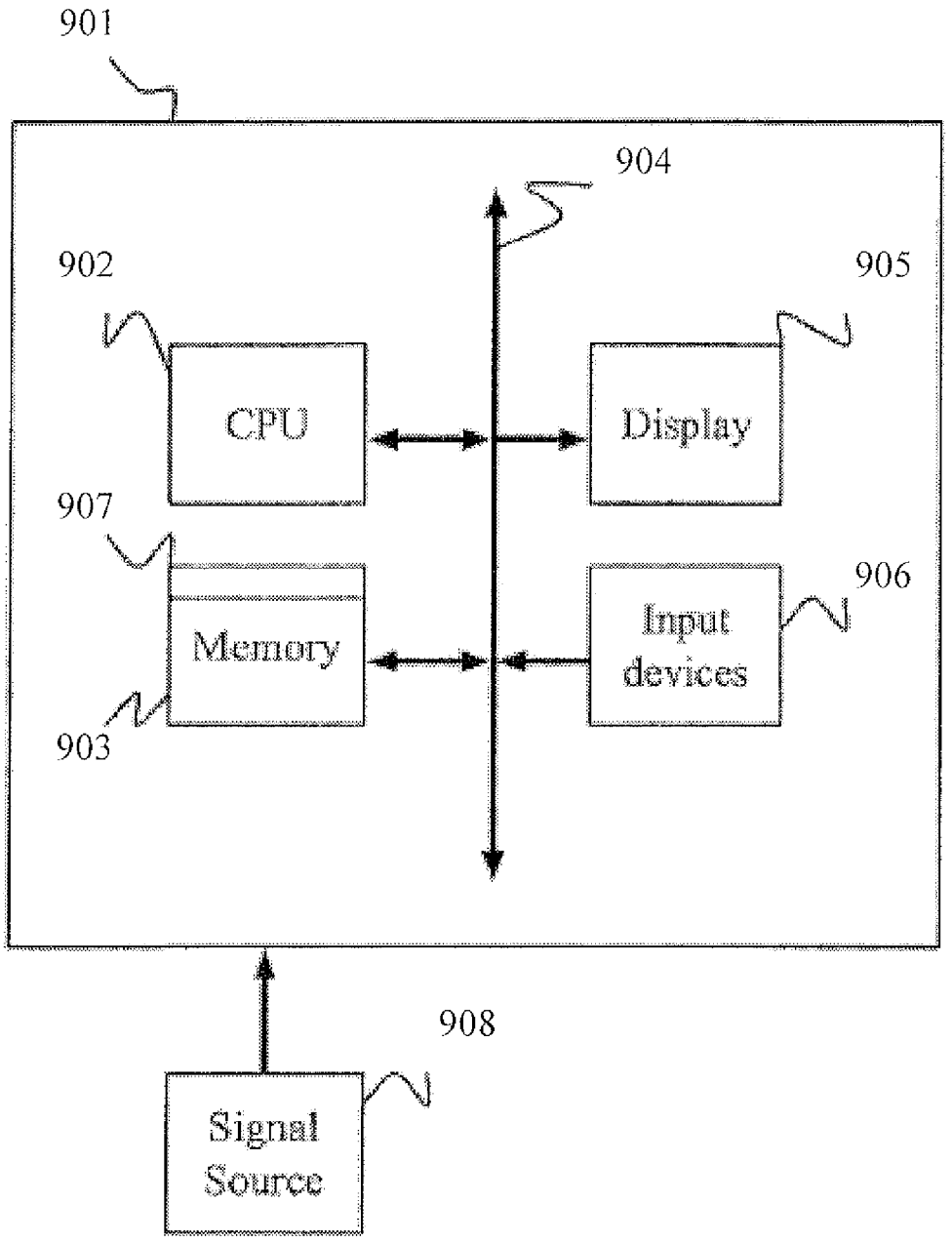

901
904
902
905
CPU
Display
907
906
Memory
Input devices
903
908
Signal Source

FIG. 9

AUTOMATED ELECTRIC VEHICLE CHARGING SYSTEM AND METHOD

CROSS-REFERENCE TO RELATED PATENT APPLICATION

[0001] This application is a Continuation-in-Part Application of U.S. application Ser. No. 13/089,827, filed on Apr. 19, 2011, which claims priority to and the benefit of Provisional Application Ser. No. 61/325,643, filed on Apr. 19, 2010, and Provisional Application Ser. No. 61/328,411, filed on Apr. 27, 2010, the disclosure of which is incorporated by reference herein in its entirety.

TECHNICAL FIELD

[0002] The present disclosure relates to automatically charging an electric vehicle, and more particularly, to a system and method for automatically charging an electric vehicle.

DISCUSSION OF RELATED ART

[0003] Electric vehicles generally conserve more energy than vehicles powered by internal combustion engines. For example, since electricity used to power electric vehicles can be produced from a variety of fuels, the use of electric vehicles allows for the conservation of scarce sources of energy by instead utilizing more abundant source of energy to produce electricity. Further, electrical energy is generated at centralized locations using a variety of fuels. This centralization increases the opportunity for the development of new and conserving methods of generating electric energy.

[0004] Efficient utilization of electrical energy depends in part on the leveling of demand on the electric power grid. For example, the peak period for energy use generally occurs during daylight hours, and late night hours are typically underutilized. This is reflected by an owner of an electric vehicle often forgetting or being unwilling to wait until late night hours to initiate the charging process for his/her electric vehicle.

[0005] Further, range anxiety presents a major obstacle to consumer acceptance of electric vehicles. Range anxiety refers to a driver's fear that he/she will not have a fully charged vehicle that meets his/her needs. For example, if a driver forgets to charge an electric vehicle at the end of the day, the driver's range of use the following day will be unpredictable. Reducing range anxiety is likely to increase the adoption rate of electric vehicles.

BRIEF SUMMARY

[0006] According to an exemplary embodiment of the present disclosure, a method for charging an electric vehicle includes identifying vehicle information corresponding to the electric vehicle based on an electronic image of the electric vehicle, retrieving from an electronically stored local database a location of a charging port on the electric vehicle based on the vehicle information, robotically moving a charging connector according to the retrieved location to engage the charging port of the electric vehicle, querying the local database to determine whether a current time corresponds to an energy efficient usage time based on energy efficient usage data received from a power grid, and initiating a charging process upon determining that the current time corresponds to the energy efficient usage time.

[0007] According to an exemplary embodiment of the present disclosure, a method for charging an electric vehicle includes identifying vehicle information corresponding to the electric vehicle based on an electronic image of the electric vehicle, retrieving from an electronically stored database a location of a charging port on the electric vehicle based on the vehicle information, and robotically moving a charging connector according to the retrieved location to engage the charging port of the electric vehicle to charge a battery.

[0008] According to an exemplary embodiment of the present disclosure, a method for charging an electric vehicle includes identifying vehicle information corresponding to the electric vehicle using a radio-frequency identification (RFID) tag mounted on the vehicle, retrieving from an electronically stored database a location of a charging port on the electric vehicle based on the vehicle information, and robotically moving a charging connector according to the retrieved location to engage the charging port of the electric vehicle to charge a battery.

[0009] According to an exemplary embodiment of the present disclosure, a system for charging an electric vehicle includes a first camera, an electronic database, a processor, and a robotic arm.

[0010] The first camera is configured to acquire an electronic image of the electric vehicle. The processor is configured to identify vehicle information corresponding to the electric vehicle based on the electronic image of the electric vehicle, and retrieve from the electronic database a location of a charging port on the electric vehicle based on the vehicle information. The robotic arm is configured to move a charging connector according to the retrieved location to engage the charging port of the electric vehicle to charge a battery.

[0011] According to an exemplary embodiment of the present disclosure, a system for charging an electric vehicle includes a radio-frequency identification (RFID) reader, an electronic database, a processor, and a robotic arm. The RFID reader is configured to identify vehicle information corresponding to the electric vehicle using an RFID tag mounted on the electric vehicle. The processor is configured to retrieve from the electronic database a location of a charging port on the electric vehicle based on the vehicle information. The robotic arm is configured to move the charging connector according to the retrieved location to engage the charging port of the electric vehicle to charge a battery.

[0012] According to an exemplary embodiment of the present disclosure, a method for charging an electric vehicle includes acquiring a plurality of images of a field of view while in a vacant state, detecting whether the electric vehicle has entered the field of view based on an analysis of the plurality of images while in the vacant state, initiating a tracking state upon detecting that the electric vehicle has entered the field of view, tracking a position and pose of the electric vehicle while the electric vehicle is in motion based on a plurality of features of the electric vehicle extracted from each image while in the tracking state, initiating an identify state upon detecting that the electric vehicle is no longer in motion, identifying a matching vehicle model candidate in a database using the position and pose of the electric vehicle in each image while in the identify state, initiating a connect state upon identifying a matching vehicle model candidate, verifying whether a charging port on the electric vehicle is in an expected location based on a most recently acquired image while in the connect state, and engaging a charging connector

into the charging port upon verifying that the charging port is in the expected location while in the connect state.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

[0013] The above and other features of the present disclosure will become more apparent by describing in detail exemplary embodiments thereof with reference to the accompanying drawings, in which:

[0014] FIG. **1** is a flowchart showing the operation of a vacant state software module, according to an exemplary embodiment;

[0015] FIGS. **2**A-**2**B are a flowchart showing the operation of a tracking state software module, according to an exemplary embodiment;

[0016] FIG. **3** is a flowchart showing the operation of an identify state software module, according to an exemplary embodiment;

[0017] FIG. **4** is a flowchart showing the operation of a connect state software module, according to an exemplary embodiment;

[0018] FIG. **5** is a flowchart showing the operation of a charging state software module, according to an exemplary embodiment;

[0019] FIG. **6** is a flowchart showing the operation of a disengage state software module, according to an exemplary embodiment;

[0020] FIG. **7** is a flowchart showing the operation of a departing state software module, according to an exemplary embodiment;

[0021] FIG. **8** is a block diagram of the vehicle charging system, according to an exemplary embodiment; and

[0022] FIG. **9** is a computer system for implementing a method of automatically charging an electric vehicle, according to an exemplary embodiment of the present disclosure.

DETAILED DESCRIPTION

[0023] Exemplary embodiments of the present disclosure will be described more fully hereinafter with reference to the accompanying drawings. Like reference numerals may refer to like elements throughout the accompanying drawings.

[0024] System Components

[0025] An exemplary embodiment of an automated electrical vehicle charging system may include a processor, a camera and an associated computer interface board (e.g., a frame grabber), a charging cable and a charging connector, and a robotic arm. The electric vehicle charging station may automatically connect to a vehicle and charge the vehicle without the need for operator action. The charging station may operate without the user having to precisely align the vehicle at the charging station, and without any specialized modifications or equipment installations made to the vehicle. For example, when a vehicle is driven up to and parked near the charging station, the charging system may recognize that the vehicle is present, identify information about the vehicle (e.g., the make, model and year of the vehicle), and determine the location of the vehicle's charging port using this information. The charging system may then automatically establish a connection with the vehicle's charging port and initiate the charging process. The charging system may utilize different charging voltages and currents, and various types of electrical connectors. Once charging is complete, the charging system may disengage the connection and monitor the vehicle to determine when it has left the charging system, allowing another vehicle to be charged.

[0026] According to an exemplary embodiment, an automated electrical vehicle charging system uses a camera to continuously monitor the space where a vehicle is to be parked for charging. The camera analyzes the image frames to identify when a vehicle moves into the camera field of view. When a vehicle is found, a sequence of images is used to track the vehicle until it is parked, and those images are used to identify information about the vehicle such as, for example, the vehicle's make, model and year. A database of three dimensional (3D) mathematical models for different vehicles and their corresponding make, model and year is compared to the camera images, similarity scores are calculated, and a vehicle having the highest similarity score is selected.

[0027] Once the make, model and year of the vehicle are determined, the location of the vehicle's charging port is obtained from a look-up in the vehicle database. The location of the charging port may be verified from the camera image of the parked vehicle, and a robotic arm may carry a charging cable with a charging connector to the vehicle's charging port, using a real-time sequence of camera images for guidance. The robotic arm may open a door covering the charging port, if present, before plugging in the charging connector. Once the charging connector is engaged in the charging port, the charging system initiates and monitors the charging process. When the charging system senses that charging is complete, the robotic arm disengages the charging connector and returns to its home position. The charging system continues to monitor and track the vehicle to determine when it has left the charging station. Once the vehicle has left the charging station, the camera monitors the space to determine when another vehicle has arrived.

[0028] The processor operates continuously and executes various software functions and controls the actions performed by the components of the charging system. The processor may be part of an embedded computer that oversees the operation of the entire charging system, including the acquisition of the camera images and control of the robotic arm, and performs the computations for image analysis and vehicle tracking and identification. The processor executes the software that performs the various functions of the charging system. The embedded computer may be based on an Intel® S5520SC workstation motherboard with an Intel® Xeon® 5500 series quad core processor operating at about 3.3 GHz, however, as will be appreciated by one having ordinary skill in the art, the embedded computer is not limited thereto. Utilization of multiple processor cores in the embedded computer allows the image processing functions, the robotic arm control, and other functions to be concurrently active without competing for processor resources (e.g., when the camera images are being used to guide the charging connector into the vehicle charging port). The embedded computer may include a vision processor board such as, for example, a Matrox® Odyssey Xpro+ scalable vision processor board, which includes a PowerPC® G4 processor with a customizable Field Programmable Gate Array (FPGA) coprocessor. The vision processor board provides highly parallel execution of many image operations such as, for example, filtering, motion detection, and matrix processing. Utilization of the vision processor board takes a portion of the computational load off of the main processors.

[0029] The vision processor board may be configured with a Camera Link single-camera full-configuration frame grabber mezzanine, which provides the interface to the camera. The Camera Link frame grabber handles the acquisition of images from the camera, and its interface provides for control of many camera operating parameters such as, for example, the frame rate and shutter speed. The interface can also be used to trigger the shutter. The shutter speed may be adjusted to compensate for changes in light levels, and to keep the images within an acceptable brightness range without being saturated.

[0030] The charging system may further include communication devices capable of sending and receiving messages to other computers or devices. The communication devices may operate via wires or wirelessly, and may connect to the Internet using the TCP/IP protocol. The communication devices may be used, for example, to download updates to the vehicle database, and/or to validate billing information with a remote accounting system. The communication devices may also be used to query the local power grid to determine the optimal times to commence charging of the vehicle. Adjusting the charging schedule based on the demand for electric energy allows for efficient and economical use of the local power grid. For example, the charging system can adjust the charging schedule based on fluctuations in the demand for electric energy occurring in the local power grid during a twenty-four hour period. As a result, the charging system can charge the vehicle when overall use of the local power grid is low (and possibly cheaper), and refrain from charging the vehicle when the overall use of the local power grid is high. Thus, the charging system may facilitate a shift in demand to the underutilized periods of electric power usage (e.g., nighttime hours) by automating the process in which vehicle owners recharge their electric vehicles, and may allow vehicle owners to designate a charging time that is beneficial to both the electric power provider and the vehicle owner. The automated process may foster the conservation of energy by increasing the willingness of drivers to accept electrically powered vehicles.

[0031] In an exemplary embodiment, the charging system maintains its own database of optimal times for electrical usage. The database can be updated via the communication devices on a periodic basis at specified time intervals, or automatically by the electrical provider whenever a change occurs. Updating the database when changes occur allows the charging system to use electricity during efficient and economical times.

[0032] The camera may be used to acquire images of a charging space at the charging station where the vehicle is to be parked during charging. The acquired images are used for vehicle tracking and identification, as well as to guide the robotic arm as it engages the charging connector into the charging port. The camera may be, for example, a monochrome, progressive scan charge-couple device (CCD) camera with 1600×1200 square pixels and the Camera Link interface, such as, for example, a Sony® XCL-U1000. However, as will be appreciated by one having ordinary skill in the art, the camera is not limited thereto. The camera may be a high-sensitivity camera (e.g., 400 lux at f/5.6) with shutter speeds of about 10 μsec, and may be operated at a frame rate of about 5 Hz to about 15 Hz, however, the camera is not limited thereto. The camera acquires images continuously, and the frame grabber places the images into a multi-frame buffer, which allows the software to process the most recent image while the next image is being acquired. The camera may be mounted in a fixed position and have a fixed viewing direction, such that the side of the vehicle including the charging port is visible when the vehicle is parked in the charging space, and the front of the vehicle is visible at some point during the parking process. A moderately wide angle lens may be used, such that entire charging station and the vehicle are within the field of view when the vehicle is parked for charging.

[0033] In an exemplary embodiment, an additional camera may be mounted on the robotic arm. The additional camera may acquire images which are used to verify the location of the charging port on the vehicle and guide the robotic arm as it engages the charging connector into the charging port. The additional camera may have a lower resolution than the main camera used to monitor the vehicle. For example, the additional camera may be a monochrome progressive scan CCD camera with 640×480 square pixels and the Camera Link interface, such as, for example, a Sony® XCL-V500. However, as will be appreciated by one having ordinary skill in the art, the additional camera is not limited thereto. The additional camera may be mounted in a fixed position on the robotic arm such that the charging connector and the charging port on the vehicle are both within the field of view. Utilization of the additional camera allows the vehicle to be parked at the charging station in a position where the charging port is not visible from the main camera.

[0034] The charging cable and the charging connector mate with the vehicle's charging port and supplies the charging voltage and current to the vehicle. The charging cable and charging connector also carry any signal lines associated with the connection. Various types of cables and connectors may be used to charge the vehicle. The charging connector is attached to the robotic arm, and the robotic arm engages the charging connector into the charging port. The charging connector may engage the charging port via various means. For example, the charging connector may be pushed straight into the charging port, and an actuator attached to the robotic arm may be used to twist the charging connector into place once it has been pushed into the charging port.

[0035] Connectors used in the charging system may be conductively coupled (e.g., directly coupled) or inductively coupled (e.g., magnetically coupled). When the connectors are conductively coupled, direct contact is made between the conductors, and the supplied voltage may be either an AC voltage or a DC voltage. When the supplied voltage is an AC voltage, a charger/regulator may be located on the charging station or on the vehicle, and may be used to convert the AC voltage to a DC voltage and to regulate the voltage and/or current as the battery is being charged. Disposing the charger/regulator on the vehicle allows the vehicle to be charged at multiple locations. When the supplied voltage is a DC voltage, a charger for voltage and current regulation may be located on the charging station. When the connectors are inductively coupled, the supplied voltage may be an AC voltage, and the conductors may be enclosed and impervious to water. In a charging system using inductively coupled connectors, grid power is first converted to a higher frequency to improve efficiency and to allow for reasonably sized connectors.

[0036] The charging cable and charging connector may be compliant with the SAE J1772 standard, which is a U.S. standard for electrical vehicle connectors maintained by the Society of Automotive Engineers. The charging cable and

charging connector may be compliant with various revisions of the SAE J1772 standard including, but not limited to older revisions (e.g., the Avcon standard) and newer revisions (e.g., the January, 2010 revision). For example, the charging connector may be a round connector about 43 mm in diameter and may contain five pins, as defined in the January, 2010 revision. The five pins are AC Line 1, AC Line 2/Neutral, Ground, Proximity Detection, and Control Pilot. According to the standard, the Proximity Detection line prevents movement of the car while the charging connector is attached, and the Control Pilot line facilitates communication for coordinating the charging level between the vehicle and the charger, as well as other information. The standard further provides safety, particularly in wet weather, by isolating the connection pins on the interior of the connector with no physical access when mated, and ensuring that there is no voltage on the pins when not mated. The standard defines two charging levels depending on whether pin **2** is used as an AC line for 240 V or Neutral for 120 V:

[0037] AC Level 1: 120 V, single phase, 16 A, (1.9 kW)

[0038] AC Level 2: 240 V, single phase, 80 A, (19.2 kW)

[0039] An example of a connector based on the January 2010 revision is manufactured by Yazaki. Other connectors are being developed by Mennekes and are expected to be included under the IEC 62196 electric vehicle standard. These connectors use three-phase AC and are capable of charging at rates used for fast charging.

[0040] For purposes of the present disclosure, it is assumed that existing charging stations monitor any signal wires present in the charging connector. For example, signal wires indicating whether a valid connection has been established, the charging level, and other status information may be used to make this information available to the charging station through a digital input. Similarly, it is assumed that an existing charging station is turned on or off via a switch or a relay controlled by the embedded computer of the present disclosure, and that any voltage or current issues may be handled by existing equipment.

[0041] The robotic arm is used to hold the charging cable and the charging connector, and to engage the charging connector into the vehicle's charging port. The robotic arm may be, for example, a six-axis arm with a reach of about 2 meters and a payload capability of about 10 kg, such as, for example, a model M-20iA/10L manufactured by FANUC® Robotics. However, as will be appreciated by one having ordinary skill in the art, the robotic arm is not limited thereto. In an exemplary embodiment, an additional camera used to verify the location of the charging port and guide the robotic arm as it engages the charging connector into the charging port may be mounted on the robotic arm. Further, an actuator used to open a cover or door on the charging port, if present, may be attached to the robotic arm.

[0042] In an exemplary embodiment, the charging station may include an RFID reader. RFID is often used for inventory control in retail stores, and is an accepted method for paying by credit card at gas stations and other establishments. The RFID reader may read an RFID tag mounted on the vehicle to identify information relating to the vehicle such as, for example, the make, model and year of the vehicle. The RFID reader may further be used to provide customer billing information for the charging transaction. The RFID reader may be a commercial embedded RFID reader such as, for example, a SkyeModule™ M10 manufactured by Skyetek®, which has a range of about **5** meters, however, the RFID reader is not limited thereto. The RFID reader may be used in place of, or in conjunction with, the computer vision software techniques described herein to identify the make, model and year of the vehicle. Exemplary embodiments may take the cost of each implementation (e.g., the cost of the RFID reader compared to the incremental cost of the added computational power used to perform the described computer vision software techniques) into consideration when determining which implementation to utilize. The RFID reader may further be used to provide billing information for the charging transaction. When RFID is utilized, a camera may still be used to track the position and pose of the vehicle, allowing for the determination of the location of the vehicle's charging port with respect to the charging station.

[0043] In an exemplary embodiment, an energy storage device may be used to provide for fast charging of the vehicle at power rates beyond the capability of the connection to the local power grid to the charging station. For example, the energy storage device may be a battery similar to the 26 kWh lithium-ion battery used in the Nissan® Leaf™, however, the energy storage device is not limited thereto. Utilization of an energy storage device allows the charging system to provide fast charging without the need for special wiring.

[0044] Exemplary embodiments may further include other components that are used in existing charging stations such as, for example, power cables and connectors of various types, voltage/current regulators, and credit card readers.

[0045] Vehicle Tracking and Recognition, and Software Architecture

[0046] The process of tracking a vehicle to determine when it has entered the charging station, and identifying information about the vehicle such as, for example, the make, model and year of the vehicle, is based on a structure-from-motion algorithm, in which a sequence of two-dimensional (2D) camera images of the moving vehicle are analyzed to construct a 3D structure, including the pose of the vehicle. An example of a structure-from-motion algorithm is described in Prokaj, J., Medioni, G., 3-*D Model Based Vehicle Recognition,* IEEE Workshop on Applications of Computer Vision (2009), and Hartley, R., Zisserman, A., *Multiple View Geometry in Computer Vision,* Cambridge University Press (2003). In an exemplary embodiment, a single camera mounted in a fixed position captures the images as the vehicle is driven into the charging space. As the vehicle moves, it appears in a different position and presents a different pose to the camera in each image frame. When tracking the vehicle, feature points on the vehicle, which appears as a rigid body, follow different trajectories as a result of the perspective projection of the 3D object (e.g., the vehicle) onto the camera image plane. Feature points between different frames may be matched and a system of equations may be generated. Solution of the equations results in a 3D structure corresponding to the vehicle.

[0047] This analysis is similar to a stereo vision system, where images of a stationary object are captured from different viewing angles to provide depth information that is lacking in any one image. In an exemplary embodiment, the viewpoint and viewing direction of each image with respect to the vehicle coordinate frame are not known in advance, and are obtained using the solution of the system of equations described above. Further, a relatively large number of image frames may be used, and the frames may be acquired at a rate that is sufficient to make the distance that the vehicle travels between successive frames relatively small, and the motion

relatively smooth. As a result, the identification of corresponding features in adjacent frames is improved compared to a traditional stereo vision system. This results in improved reliability when recognizing whether a feature is no longer visible (e.g., a feature that is occluded in certain views).

[0048] The software used for the charging system may be built on an operating system platform that supports hard real-time processing such as, for example, Wind River Linux 3.0 with Wind River Real-Time Core for Linux from Wind River Systems, Inc., however, the software is not limited thereto. The software architecture may be organized as a set of system states, and each state may be associated with a processing module that is executed when the charging system is in that state. The system states are discussed in detail with reference to FIGS. **1** to **7**.

[0049] If a module that is currently executing changes the system state, that module is exited, and the module for the new state is executed. The architecture also includes a database containing vehicle information such as, for example, the make, model, and year of different vehicles, which supports the processing modules in identifying the vehicle and locating its charging port.

[0050] The system states and the associated processing modules are described herein. The states are listed below in the order they are frequently traversed. For example, a vehicle may first be driven into the field of view of the camera, proceed through the charging process, and then leave the charging space. However, as will be appreciated by one having ordinary skill in the art, the order of the states is not limited thereto, and the states may be traversed in any order.

[0051] FIG. **1** is a flowchart showing the operation of the vacant state software module, according to an exemplary embodiment.

[0052] The vacant state is the initial or idle state of the charging system. In the vacant state, no vehicle is at or approaching the charging station. Camera images are obtained and analyzed in the vacant state to detect whether a vehicle has entered the field of view of the camera. When a vehicle is detected, the system state is set to the tracking state.

[0053] In the vacant state, when there is no vehicle in the charging space, the image frames acquired by the camera are used to estimate the background using the mode of the images over the preceding several seconds. A vehicle coming into the camera field of view is recognized using a background-subtraction motion detector technique, where the area that changes is large enough to represent a vehicle and is completely within the field of view. When a vehicle is found, the images are saved until there is no motion of the vehicle (e.g., the vehicle is parked). The motion may be paused and restarted, resulting in additional images being added to the sequence until the vehicle stops again.

[0054] Referring to FIG. **1**, when the system is in the vacant state, no vehicle has been detected at the charging station, and no vehicle has been detected approaching the charging station. In the vacant state, each camera frame is processed as it is acquired to determine whether a moving vehicle is present. For example, if the system is not currently monitoring a moving vehicle (block **101**), the next camera frame is obtained (block **102**). Background subtraction is used to detect whether an object is present (blocks **103**-**105**). If an object is detected (block **106**), the blob of pixels representing the object is monitored. If the object is completely contained within the field of view (e.g., no part of the object is at edges of the image) (block **107**), is large enough to be a vehicle (block **108**), and is moving (e.g., compared to the previous frame) (block **109**), the system state is set to the tracking state (block **110**). If an object is not found (block **106**), is not completely contained within the field of view (block **107**), is not large enough to be a vehicle (block **108**), or is not moving (block **109**), the background is updated (block **105**), and it is determined whether the database should be checked for updates (block **111**). If it is not time to check for updates, the next camera frame is obtained (block **102**). If it is time to check for updates, a thread is initiated which sends a message via the communication link to determine whether updates to the database are available (blocks **112**, **113**). The thread may execute at a low priority in a background mode. If updates are available, they are downloaded and automatically installed (blocks **114**, **115**).

[0055] FIGS. **2**A-**2**B are a flowchart showing the operation of the tracking state software module, according to an exemplary embodiment.

[0056] In the tracking state, the trajectory of the vehicle is tracked from frame to frame. Features are identified on the vehicle and compared with features from previous frames to establish a track for the features. The data for each camera frame is saved for subsequent further processing. Once the vehicle has been parked, the system state is set to the identify state. Referring to FIGS. **2**A-**2**B, as each frame is acquired by the camera (block **201**), pre-processing is performed on the frame to provide preliminary analysis of the vehicle motion, and to identify and track the feature points used by the structure-from-motion algorithm. Background subtraction is used to detect whether the vehicle is present (blocks **202**, **203**). If the vehicle is not found, or if the vehicle was previously found but has exited the field of view, the system state is set to the vacant state (block **204**). If the vehicle is found, the center of the vehicle in the image is computed (block **205**), and the blob of pixels representing the vehicle is compared with the previous frame to determine whether the vehicle is still moving (block **206**). If the vehicle has not moved for a certain period of time, the vehicle is considered to be parked, and the system state is set to the identify state (blocks **208**, **209**). If the module has not switched to a new state, the feature matching and tracking processing for the current image frame is performed.

[0057] Corner detection may be used to extract features in each frame for tracking the vehicle motion and for identifying the make, model and year of the vehicle (block **207**). For example, a Harris corner detector may be used. An example of a Harris corner detector may be found in Harris, C., Stephens, M. J., *A Combined Corner and Edge Detector,* Proceedings, Alvey Vision

[0058] Conference pp. 147-152 (1988). The Harris corner detector is based on the local autocorrelation matrix, whose eigenvalues represent a measure of the change in intensity in the two principal directions defined by the eigenvectors. If both eigenvalues are small, there is little change in any direction (e.g., the intensity is nearly constant over that part of the image). If one eigenvalue is large while the other is small, it indicates an edge perpendicular to the first eigenvector. If both eigenvalues are large, it indicates a corner. The threshold may be set so that a moderately sparse set of corner features is extracted. Once candidate features are identified using, for example, the Harris corner detector (block **207**), each one is compared for correspondence with features and tracks from previous frames using a feature matching technique, as shown in FIG. **2**B.

[0059] If a feature in the current frame matches a previously established feature track, it is added to that track. Since the camera frame rate is selected to keep the apparent motion small from one frame to the next, and because the vehicle is physically constrained by the wheels on the ground plane, the vehicle trajectory and any feature tracks are smooth. Features are matched across image frames using, for example, a Bayesian maximum a posteriori (MAP) technique to find the feature in the current frame that best matches a feature in a previous frame. Once a match is found, a track is established, identifying the relationship between the features and their positions in their corresponding frames. Features in the current frame are also tested against previously established tracks and are added to the track if a match is found. For example, the search for matches starts by projecting each track found in previous frames (block **211**) to estimate the position where the feature would be located in the current frame (block **212**). The Bayesian prior probability is taken as a circular distribution centered at that location, decreasing with distance, from a maximum at the center out to a radius of about 1.5 times the apparent motion from the last frame of the track. The likelihood function is calculated as a normalized cross-correlation between features in the two frames (block **213**), and the feature in the current frame with the maximum a posteriori probability (block **214**), above a certain threshold (block **216**), is selected as the match and added to the track (block **217**). This is done for each track (block **215**), and for each feature in the current frame (blocks **210**, **218**).

[0060] If no matching track is found, it is compared to features in previous frames, and if a match is found, a new track is created. The data generated for each camera frame is saved for subsequent further processing. That is, after all previous tracks have been examined, any unmatched features from the previous few frames are examined for matching with features in the current frame (block **219**). The process is similar to the process used for tracks, except that the center of the prior distribution is estimated from the feature location in the previous frame projected by the motion of the center of the blob of vehicle pixels from the previous frame to the current frame (blocks **220**, **221**). The feature in the current frame with the maximum a posteriori probability (block **222**), above a certain threshold (block **224**), is selected as the match, and a new track is established (block **225**) by doing this for each feature (block **223**). Any features in the current frame that are not used in a track remain unmatched.

[0061] FIG. **3** is a flowchart showing the operation of the identify state software module, according to an exemplary embodiment.

[0062] In the identify state, the feature matching/tracking results saved for each frame in a structure-from-motion algorithm are applied to determine the position and pose of the vehicle in each frame. The vehicle database is then searched to find the best match of pose-corrected features in the database with the frame data. Once the best match is determined, the system state is set to the connect state.

[0063] Once the structure-from-motion algorithm obtains the position and pose of the vehicle as seen in each of the camera frames, the position and pose are used to identify the make, model and year of the vehicle. The position and pose of the vehicle are used to match the feature information extracted in each frame with the 3D models in the vehicle database. Each 3D vehicle model may be translated and rotated to match the pose of the vehicle in the frame, converted to a 2D image, and matched with the 2D features seen in the frame. As a result, the search may be performed in 2D rather than 3D, which may reduce the search requirements. Referring to FIG. **3**, a motion detector algorithm is used to test each frame as it is acquired by the camera determine whether the vehicle is moving again (blocks **301**, **302**). If the vehicle is moving, the system state is set to the tracking state (block **304**), where the system continues to track the vehicle and its feature points, and the identify state is exited (block **305**).

[0064] If the vehicle is not moving, the structure-from-motion algorithm is used to determine the position and pose of the vehicle for each frame collected in the tracking state. For example, once feature correspondence between frames has been established, a starting frame is selected based on the number and quality of matching features with other frames (block **306**). A second frame, moving forward in the sequence, is then chosen (block **307**), and those features that match the first frame are used to generate a system of linear equations (block **308**) which may be used to obtain the change in position and pose of the vehicle relative to the first frame (block **309**). The second frame is chosen both for its matching features with the first frame, and for the apparent motion of those features from the first frame (block **310**). While the camera frame rate is selected to keep the apparent motion small from one frame to the next for accurate feature tracking, the use of frames with small apparent motion may enhance noise in the solution of the equations. For motion reconstruction, the frame is selected so that the apparent motion produces a well formed set of equations that can be solved with minimal noise. The process repeats incrementally, choosing a next frame and computing the vehicle position and pose, until the end of the frame sequence is reached (blocks **307-310**). The process is again repeated, working back from the starting frame to the beginning of the frame sequence. At this point, the position and pose of the vehicle in each computed frame are known with respect to the starting frame. The position and pose are related to the charging station coordinate system, or the camera coordinate system, by modeling the vehicle to have fixed rear wheels with rotation around the vertical axis at the center of the rear axel and fitting the vehicle trajectory through the computed position and pose data points.

[0065] The change in position and pose from one frame to the next is calculated by solving for F, the fundamental matrix of the epipolar geometry relating the two frames [see, for example, Hartley, R., Zisserman, A., *Multiple View Geometry in Computer Vision,* Cambridge University Press (2003)]. F is a 3×3 matrix of rank 2 that can be constructed from eight parameters, including the translation and rotation of the vehicle between the frames. The equations are generated using the equation $x'^{T} Fx=0$, where:

[0066] x is a 3×1 matrix containing the coordinates of a feature point in the image plane of the first frame, and

[0067] x'^{T} is the transpose of the 3×1 matrix containing the coordinates of the corresponding feature point in the second frame.

[0068] Each pair of matching feature points produces one equation to solve for the eight variables, with one additional constraint that the vehicle motion is confined to the ground plane. Each pair of frames has at least seven matching features. The over-constrained problem is solved in a straight forward manner using, for example, Singular Value Decomposition (SVD). Once a solution is found, the feature correspondences are checked to determine that they are on or near their epipolar lines [see, for example, Hartley, R., Zisserman, A., Multiple View Geometry in Computer Vision, Cambridge

University Press (2003)]. The check for outliers may be done on a statistical basis using, for example, the RANSAC algorithm [see, for example, Fischler, M., Bolles, R., *RANdom SAmpling Consensus: a Paradigm for Model Fitting with Application to Image Analysis and Automated Cartography,* Commun. Assoc. Comp. Mach., 24:381-395 (1981)] (block **311**). Outliers are removed and the solution is used to guide the search for additional correspondences (block **312**). The computations used to determine the vehicle position and pose are repeated.

[0069] When it is determined that there are no more significant changes (block **313**), the vehicle database is searched for a model of a vehicle having the best matching make, model and year. In performing the search, a similarity figure of merit is accumulated over all camera frames used in the structure-from-motion algorithm. For each frame (block **314**), each 3D model in the database is rotated to the vehicle pose for that frame, and the 3D model features are projected onto the 2D plane corresponding to the camera image plane (block **316**). The similarity factors are then computed in 2D (block **317**). This process is repeated for each frame used in the structure-from-motion algorithm (blocks **314**, **319**), and for each make, model and year in the database (blocks **315**, **318**). When finished, the system state is set to connect state (block **322**). If no valid match is found, the vehicle operator is alerted to enter the make, model and year manually (e.g., via a keypad) (block **321**).

[0070] FIG. **4** is a flowchart showing the operation of the connect state software module, according to an exemplary embodiment. In the connect state, it is first verified whether the vehicle charging port is in its expected location and is accessible. Camera images are then used to direct the robotic arm towards the charging port. Charging protocols, including, for example, a fast charge protocol, are verified. Once completed, the system state is set to the charging state.

[0071] Referring to FIG. **4**, the location of the vehicle charging port is obtained from the vehicle database, along with information about the direction from which the charging connector is to be inserted (block **401**). The latest camera frame is analyzed to validate the location of the charging port and to verify that the charging port is within the range of the robotic arm carrying the charging connector (block **402**). Since the position and pose of the charging port are known to a good approximation, and since the 3D model can be rotated, translated and scaled to match the pose and position of the charging port, the search space is small, and correlation may be used to identify the charging port. A path is then calculated for the robotic arm to insert the charging connector into the charging port, providing for proper direction as the charging connector engages the charging port (block **403**). If a cover or door covers the charging port, the robotic arm may open the cover or door. The robotic arm is then directed to move along the calculated path. While moving along the path, camera frames are analyzed to accurately determine the relative position of the charging port and the charging connector, and to make adjustments to the position of the charging connector on the robotic arm as it approaches the charging port (blocks **405-407**). The camera frames may be analyzed, for example, using a correlation technique as described above. Once the charging connector has been inserted into the charging port, the system state is set to the charging state (block **408**). In an exemplary embodiment, an additional camera may be mounted on the robotic arm to guide the charging connector into the charging port. Steps similar to those described in reference to FIG. **4** may be used in conjunction with the additional camera. In this embodiment, the charging connector appears stationary in the camera image and the charging port on the vehicle appears to move.

[0072] FIG. **5** is a flowchart showing the operation of the charging state software module, according to an exemplary embodiment.

[0073] In the charging state, the charging process is initiated and monitored. Once the charging process is complete, charging voltage/current is turned off, and the system state is set to the disengage state.

[0074] Referring to FIG. **5**, the charging system outputs a binary output such as, for example, a DC signal voltage or a relay control signal to the existing charging station equipment. The binary output indicates that the charging connector has been inserted into the charging port and that the charging voltage/current may be turned on (block **501**). Once the charging connector has been inserted into the charging port, the local power grid is queried (block **502**). The local power grid is queried until it is determined that it is an efficient time for charging the vehicle (e.g., energy efficient usage time) (block **503**). Determining an efficient time for charging the vehicle is based on energy efficient usage data received from the local power grid. Energy efficient usage data is based on fluctuations in the demand for electric energy on the local power grid, and may include both daytime hours and nighttime hours. If it is determined that it is not an efficient time for charging the vehicle (e.g., an energy inefficient usage time occurring during a period of high electrical demand), the charging system is turned off if in use and a query time delay is set (block **504**), and the local power grid is queried again using the query time delay (block **502**). If it is determined that it is an efficient time for charging the vehicle (e.g., an energy efficient usage time occurring during a period of low electrical demand), the charging process is commenced (block **505**). The monitoring of signal wires in the charging connection may be performed by the existing equipment, or by components integrated into the charging system. For example, when the monitoring of signal wires is performed by existing equipment, digital inputs in the existing equipment may be continuously monitored, and the binary output may be turned off when the existing equipment signals that charging has been completed (blocks **506**, **507**). Once charging is complete, the system state is set to the disengage state (block **508**). Multiple queries can be made during a charging session to enable and disable the charging process to ensure that the charging process is efficient and economical. The local power grid may be re-queried at pre-determined intervals that may be defined by the user. For example, the charging system may re-query the local power grid every fifteen minutes, every hour, every three hours, or at any other desired interval. The vehicle is continuously charged until the charging process is complete and the system state is set to the disengage state (block **508**), or until it is time to re-query the local power grid (block **509**). If it is determined that it is no longer an efficient time for charging (e.g., a period of low electrical demand has switched to a period of high electrical demand), the local power grid is continuously re-queried until it is determined that it is once again an efficient time for charging (blocks **502-505**) (e.g., a period of high electrical demand has switched to a period of low electrical demand).

[0075] In an exemplary embodiment, the communication devices retrieve optimal usage data from the local power grid and store this data in a database in the charging system. For

example, referring to FIG. **5**, rather than querying the local power grid at blocks **502** and **509**, a database in the charging system may be queried. The optimal usage data stored in the database may be updated periodically by either contacting the local power grid at specified intervals, or by automatically downloading updated optimal data from the local power grid when a change is made to the optimal data at the local power grid. Utilization of the database eliminates the need to communicate with the local power grid each time the charging process is initiated, and regularly updating the database based on changes made at the local power grid ensures that the optimal data stored in the database is current. Updating and querying the database often allows the charging system to react appropriately to unforeseen changes that may occur in the status of the local power grid.

[0076] In an exemplary embodiment, charging profiles may be utilized to allow the user to customize a variety of charging preferences. For example, charging profiles may include a "fast charging" profile, an "economical" profile, and a "balanced" profile, however the charging profiles are not limited thereto.

[0077] Selecting the "fast charging" profile results in the vehicle being continuously charged to completion regardless of whether it is efficient and economical to do so. For example, when the "fast charging" profile is selected, the vehicle will be charged during both periods of low electrical demand at the local power grid as well as periods of high electrical demand at the local power grid.

[0078] Selecting the "economical" profile results in the vehicle only being charged when it is efficient and economical to do so. For example, when the "economical" profile is selected, the vehicle will only be charged during periods of low electrical demand at the local power grid.

[0079] Selecting the "balanced" profile gives the user greater control of when the charging system charges the vehicle. For example, when the "balanced" profile is selected, the vehicle may be charged during different periods of electrical demand at the local power grid based on a user-defined charge level threshold. For example, if the user sets the charge level threshold to 50%, the charging system will charge the vehicle during both periods of low and high electrical demand at the local power grid while the charge level of the vehicle is below 50%. Once the charge level reaches 50%, the charging system will only charge the vehicle during periods of low electrical demand at the local power grid. The charge level threshold may be set by the user, and is not limited to 50%. Further, when the "balanced" profile is selected, the vehicle may be charged during different periods of electrical demand at the local power grid based on a user-defined price threshold. Utilization of a price threshold allows the user to finely tune when the vehicle is to be charged. For example, if the user sets the price threshold to 8 cents per kilowatt hour, the charging system will charge the vehicle regardless of whether a period of electrical demand at the local power grid is defined as a low electrical demand period or a high electrical demand period, as long as the price per kilowatt hour does not exceed 8 cents. Once the price per kilowatt hour exceeds 8 cents, the charging system will refrain from charging the vehicle. The price threshold may be set by the user, and is not limited to 8 cents per kilowatt hour. In an exemplary embodiment, the user may utilize a combination of the charge level threshold and the price threshold when setting the periods during which the vehicle is to be charged.

[0080] FIG. **6** is a flowchart showing the operation of the disengage state software module, according to an exemplary embodiment.

[0081] In the disengage state, the charging connector is disengaged from the vehicle's charging port, and the robotic arm is returned to its home position. Once completed, the system state is set to the departing state.

[0082] Referring to FIG. **6**, a path is calculated for the robotic arm to disconnect the charging connector from the charging port and return to its home position (block **601**). If a cover or door covers the charging port, the robotic arm may close the cover or door. The robotic arm and robotic actuator used to close the cover or door, if present, is then directed to move along the calculated path and return to its home position (blocks **602-604**). When finished, the system state is set to the departing state (block **605**).

[0083] FIG. **7** is a flowchart showing the operation of the departing state software module, according to an exemplary embodiment.

[0084] In the departing state, the vehicle is tracked as it moves away from the charging station. Once the vehicle has left the charging station, the system state is set to the vacant state.

[0085] Referring to FIG. **7**, a camera frame is obtained (block **701**). The pixels corresponding to the vehicle are obtained based on the known position of the vehicle (block **702**). The next camera frame is then obtained (**703**), and the charging system continues to track the vehicle trajectory using a cross-correlation of the vehicle image from one frame to the next (blocks **704**,**705**). The estimation of the position of the vehicle in the second frame results in an efficient search. It is then determined whether the vehicle is leaving the field of view (block **706**). If the vehicle is not leaving the field of view, the tracking of the vehicle continues (blocks **703-705**). If the vehicle is leaving the field of view, the system state is set to the vacant state (block **707**).

[0086] In an exemplary embodiment, a database including information about various vehicles may be maintained and used with the charging system. The information may be stored, for example, based on the make, model and year of each vehicle, and may include a 3D model of the vehicle and information about the vehicle's charging port. The 3D model mathematically describes the shape of the vehicle and the location and characteristics of key features that may be used to identify the make, model and year of the vehicle. For example, key features may include, but are not limited to, windows, doors, lights, handles and/or bumpers on the vehicle. The 3D models may be represented using a vehicle-based coordinate system, which may be translated to coordinates based on the charging station once the position and pose of the vehicle are determined. Information stored in the database relating to the vehicle's charging port may include, but is not limited to, the position and pose of the charging port on the vehicle, as well as the type of coupling, the connector type, the direction from which the connector is inserted, the presence of a cover or door and how it is opened, the charging voltages and currents for normal and fast charging, and any connection protocols and/or signal wires that apply to the vehicle. The database may be created and maintained on a remote computer. The data in the database may initially be preloaded in the charging system, and the charging system may periodically check for updates via the communication link and automatically download and install the updates.

[0087] FIG. **8** is a block diagram of the vehicle charging system, according to an exemplary embodiment.

[0088] Referring to FIG. **8**, an exemplary embodiment of the vehicle charging system **800** includes a processor **802**, a first camera **802**, an RFID reader **803**, a robotic arm **804** including a charging connector **805**, a second camera **806** and an actuator **807**, and a communication link **808** connected to a data bus **809**. The processor **801** may be used to implement the computer vision software techniques described above. The first camera **802** may acquire a plurality of images of a field of view. The RFID reader **803** may receive customer billing information from an RFID tag mounted on the vehicle and transmit the customer billing information to a remote billing system. The robotic arm **804** may automatically engage the charging connector **805** into a charging port of a vehicle. The actuator **807** disposed on the robotic arm **804** may open a door covering the charging port of the vehicle prior to engaging the charging connector **805** into the charging port, and close the door upon disengaging the charging connector **805** from the charging port. The second camera **806** disposed on the robotic arm **804** may acquire an additional plurality of images having a viewpoint different from the plurality of images of the field of view. The additional plurality of images includes a view of the charging connector **805** and the charging port. The communication link **808** may check for and download updates to a database of the vehicle charging system **800**.

[0089] Referring to FIG. **9**, according to an exemplary embodiment of the present disclosure, a computer system **901** for automatically charging an electric vehicle can comprise, inter alia, a central processing unit (CPU) **902**, a memory **903** and an input/output (I/O) interface **904**. The computer system **901** is generally coupled through the I/O interface **904** to a display **905** and various input devices **906** such as a mouse and keyboard. The support circuits can include circuits such as cache, power supplies, clock circuits, and a communications bus. The memory **903** can include random access memory (RAM), read only memory (ROM), disk drive, tape drive, etc., or a combination thereof. Exemplary embodiments of present disclosure may be implemented as a routine **907** stored in memory **903** (e.g., a non-transitory computer-readable storage medium) and executed by the CPU **902** to process the signal from the signal source **908**. As such, the computer system **901** is a general-purpose computer system that becomes a specific purpose computer system when executing the routine **907** of the present disclosure.

[0090] The computer platform **901** also includes an operating system and micro-instruction code. The various processes and functions described herein may either be part of the micro-instruction code or part of the application program (or a combination thereof) which is executed via the operating system. In addition, various other peripheral devices may be connected to the computer platform such as an additional data storage device and a printing device.

[0091] Having described exemplary embodiments for an automated electrical vehicle charging system and method, it is noted that modifications and variations can be made by persons skilled in the art in light of the above teachings. It is therefore to be understood that changes may be made in exemplary embodiments of the disclosure, which are within the scope and spirit of the disclosure as defined by the appended claims. Having thus described exemplary embodiments of the disclosure with the details and particularity required by the patent laws, what is claimed and desired protected by Letters Patent is set forth in the appended claims.

What is claimed is:

1. A method of charging an electric vehicle, comprising:

identifying vehicle information corresponding to the electric vehicle based on an electronic image of the electric vehicle;

retrieving from an electronically stored local database a location of a charging port on the electric vehicle based on the vehicle information;

robotically moving a charging connector according to the retrieved location to engage the charging port of the electric vehicle;

querying the local database to determine whether a current time corresponds to an energy efficient usage time based on energy efficient usage data received from a power grid; and

initiating a charging process upon determining that the current time corresponds to the energy efficient usage time.

2. The method of claim **1**, wherein the energy efficient usage data is based on fluctuations in demand for electrical energy at the power grid.

3. The method of claim **1**, further comprising:

re-querying the power grid or the local database at specified time intervals during the charging process; and

suspending the charging process upon determining that the current time does not correspond to the energy efficient usage time.

4. The method of claim **1**, further comprising:

updating the local database by querying the power grid at specified time intervals.

5. The method of claim **1**, further comprising:

updating the local database automatically upon detecting a change at the power grid.

6. The method of claim **1**, further comprising:

setting a charging profile, wherein the battery is charged based on the charging profile.

7. The method of claim **6**, wherein the charging profile is a fast charging profile, and the battery is charged when the current time corresponds to either the energy efficient usage time or an energy inefficient usage time.

8. The method of claim **6**, wherein the charging profile is an economical profile, and the battery is charged only when the current time corresponds to the energy efficient usage time.

9. The method of claim **6**, wherein the charging profile is a balanced profile having a charge level threshold, the battery is charged when the current time corresponds to either the energy efficient usage time or an energy inefficient usage time while a charge level of the battery is below the charge level threshold, and the battery is charged only when the current time corresponds to the energy efficient usage time while the charge level of the battery is above the charge level threshold.

10. The method of claim **6**, wherein the charging profile is a balanced profile having a price threshold, the battery is charged when the current time corresponds to either the energy efficient usage time or an energy inefficient usage time while a price of electrical energy does not exceed the price threshold, and the battery is not charged when the current time corresponds to either the energy efficient usage time or the energy inefficient usage time while the price of electrical energy exceeds the price threshold.

11. A method for charging an electric vehicle, comprising:
identifying vehicle information corresponding to the electric vehicle based on an electronic image of the electric vehicle;
retrieving from an electronically stored database a location of a charging port on the electric vehicle based on the vehicle information; and
robotically moving a charging connector according to the retrieved location to engage the charging port of the electric vehicle to charge a battery.

12. The method of claim **11**, further including querying the database to determine whether a current time corresponds to an energy efficient usage time based on efficient energy usage data received from a power grid; and
initiating a charging process upon determining that the current time falls within a period of energy efficient usage time.

13. The method of claim **11**, further comprising:
acquiring a plurality of two-dimensional (2D) images of a field of view;
determining whether the electric vehicle has entered the field of view based on an analysis of the plurality of images;
extracting a plurality of features of the electric vehicle from each image; and
tracking a position and pose of the electric vehicle while the electric vehicle is in motion using the extracted features.

14. The method of claim **13**, further comprising:
constructing a three-dimensional (3D) model of the electric vehicle using the plurality of 2D images, wherein
identifying the vehicle information is based on a comparison of features in the 3D model of the electric vehicle with corresponding features in a plurality of 3D vehicle model candidates stored in the database.

15. The method of claim **13**, further comprising:
rotating each of a plurality of three-dimensional (3D) vehicle model candidates stored in the database to match a pose of the electric vehicle in each of the plurality of 2D images; and
converting each rotated 3D vehicle model candidate to a 2D vehicle model candidate, wherein identifying the vehicle information is based on a comparison of features in each of the 2D plurality of images with corresponding features in each 2D vehicle model candidate.

16. The method of claim **13**, wherein the position and pose of the electric vehicle are different in each of the plurality of 2D images, and the position and pose of the electric vehicle in each image are used to identify the vehicle information.

17. The method of claim **13**, further comprising:
acquiring an additional plurality of 2D images, wherein the additional plurality of 2D images have a viewpoint different from the plurality of 2D images of the field of view, and include the charging connector and the charging port;
verifying the location of the charging port on the electric vehicle using the additional plurality of 2D images; and
guiding the charging connector towards the charging port using the additional plurality of 2D images.

18. A system for charging an electric vehicle, comprising:
a first camera, configured to acquire an electronic image of the electric vehicle;
an electronic database;
a processor, configured to identify vehicle information corresponding to the electric vehicle based on the electronic image of the electric vehicle, and retrieve from the electronic database a location of a charging port on the electric vehicle based on the vehicle information; and
a robotic arm, configured to move a charging connector according to the retrieved location to engage the charging port of the electric vehicle to charge a battery.

19. The system of claim **18**, further comprising:
a communication device, configured to query the electronic database to determine whether a current time corresponds to a period of low electrical demand or a period of high electrical demand based on fluctuations in demand for electrical energy at the power grid.

20. The system of claim **18**, further comprising:
a second camera disposed on the robotic arm, wherein
the first camera is further configured to acquire a plurality of images of a field of view,
the processor is further configured to determine whether the electric vehicle has entered the field of view based on an analysis of the plurality of images, extract a plurality of features of the electric vehicle from each image, and track a position and pose of the electric vehicle while the electric vehicle is in motion using the extracted features, and
the second camera is configured to acquire an additional plurality of images, wherein the additional plurality of images have a viewpoint different from the plurality of images of the field of view and include the charging connector and the charging port, and are used to verify the location of the charging port on the electric vehicle and guide the charging connector towards the charging port.

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