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10 **ENERGY MANAGEMENT SYSTEM FOR VEHICLES HAVING LIMITED
ENERGY STORAGE**

Field of the Invention

The Energy management system of the present invention relates generally to designs for range and performance improvement on modern vehicles hvaing alternative energy storage systems of limited capacity. More particularly, the invention provides for monitoring and assessment of parameters for energy storage system status, vehicle status and multiple driving profiles for determining time, mileage or location of energy system exhaustion, most efficient routes to destination, alternative destinations for recharging the energy system and efficiency improvements for vehicle operation.

25 **Background of the Invention**

Environmental pollution is requiring the development and implementation of alternatively powered vehicles to supplement or replace present conventional internal combustion powered passenger vehicles. Recent developments in the technology of electric and other alternative energy vehicles allows performance of those vehicles to approach that of internal combustion engine powered vehicles in all areas with the exception of driving range. Using electric vehicles as an example, present battery technology limits the amount of onboard energy storage available for electric vehicles and the likelihood that limited locations having recharging

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1 facilities will be available in the near term requires
systems integrated in the vehicle to inform the driver of
battery status and driving range available or,
alternatively, destinations within range of the vehicle.

5 Various battery management systems have been proposed
in the prior art to estimate the state of charge of the
vehicle battery and remaining vehicle range. Examples of
these systems are described in the paper by C.C. Chan and
K.C. Chu, "Intelligent Battery Management System,"
10 presented at the Electric Vehicle Symposium 9, November
13-16, 1988 in Toronto, Ontario, Canada and the SAE
technical paper by A.F. Burke, "Evaluation of State of
Charge Indicator Approaches for E.V.'s," presented at the
International Congress and Exposition of the SAE, Detroit,
15 Michigan, February 27-March 3, 1989. These systems are
typically very limited in the information provided to the
electric vehicle user.

For some time navigation systems have been under
development for use with ground vehicles. Exemplary of
20 the prior art in this field are U.S. Patent Nos. 4,926,336
to Yamada, 4,984,168 to Meukirchner, 4,992,997 to Nimura
et al. and 5,121,326 to Moroto et al. Information
provided by such prior art navigation systems can be of
particular use to electric vehicle operators, however,
25 supplementing of data and calculation routines of the
prior art navigators to incorporate information critical
for electric vehicle operation would allow use of a
navigation system to supply information to the electric
vehicle operator for energy efficient route planning and
30 alternative route planning where insufficient range is
available from the battery pack in the vehicle.

The present invention combines and improves the prior
art systems to provide an energy management system for
optimum use of an electric vehicle by allowing the driver
35 to select performance modes, driving profiles and
destinations while informing the driver of vehicle status,

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1 range, navigational route capability and vehicle efficiency control.

Summary of the Invention

5 The present invention is applicable to vehicles employing limited energy storage systems including, but not limited to, battery systems, inertial energy systems and hybrid electric systems. The embodiment disclosed herein employs a battery storage system. The electric vehicle
10 energy management system incorporates an electronics module having a microcontroller for sensing, control and calculation, and memory for maintaining driving profiles, vehicle status information and mathematical models for the vehicle and battery systems. A battery sensor package
15 provides status information to the electronic module for the battery voltage, temperature and current for use with the battery model. Vehicle sensor inputs to the electronic module include temperature inside the vehicle, outside air temperature, temperature of the motor
20 controller, temperature of the motor, speed of the vehicle and acceleration of the vehicle for use with the vehicle model. A driver interface, which incorporates an accelerator pedal and a brake pedal for motion control of the vehicle and a plurality of control buttons for control
25 of the electronic module and a text display for output from the module to the driver. Normal display functions for safe operation of the vehicle, such as speedometer, odometers and battery status are provided from the electronic module, using standard analog or digital
30 displays in an instrument cluster on the vehicle dashboard.

The microcontroller employs the data received from the battery sensor inputs for range calculations based on the battery model stored in the memory. The battery model
35 includes experimentally determined formulas or tables describing the voltage and current relationship over the range of allowable depths of discharge and the model of



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1 cycle life based on battery charge and discharge history.
The vehicle model incorporates the information from the
battery model and the efficiencies of the electric motor,
transmission and motor controller as functions of speed,
5 load and temperature as well as losses due to rolling
friction, aerodynamics and hill climbing. The
microcontroller employs the vehicle model for range and
efficiency calculations based on the vehicle sensor
inputs. The driving profiles stored in the memory are
10 employed by the microcontroller for calculation of power
consumption based on "standardized" driving profiles, such
as stop and go, freeway cruising, and hill climbing, or
profiles obtained by memorizing the power consumption
history of trips unique to the driver of the vehicle. The
15 microcontroller provides calculation for the energy
management system to predict range of the electric vehicle
based on the driving profile and speed selected by the
driver through the driver interface.

In addition to the stored profiles, the energy
20 management system interfaces with a vehicle navigator
employing a database of street routes and other static and
dynamic navigation information for calculation of energy
efficient routes to a destination based on the vehicle
model and alternative routes to battery charging stations
25 if the battery condition does not allow sufficient range
to reach the desired destination.

The energy management system through its
microcontroller provides active control of vehicle systems
including the charging system for the battery pack,
30 internal and external lighting systems, heating,
ventilating and air conditioning systems for the vehicle
and the drive motor controller.

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1 **Brief Description of the Drawings**

The present invention is best understood with reference to the following drawings and accompanying detailed description wherein:

5 FIG. 1 is a block diagram of the generalized energy management system and the systems and sensors interfaced to the EMS.

FIG. 2 is a schematic of an embodiment of the energy management system employing a standard microcontroller.

10 FIGS. 3a and 3b are a block diagram of the menu hierarchy for the text display of the driver interface from the energy management system.

FIGS. 4a and 4b are a flow diagram for range prediction by the energy management system.

15 FIGS. 5a and 5b are a flow diagram for selection of the driving mode.

FIGS. 6a and 6b are a flow diagram of the general control program for the energy management system microcontroller.

20 FIGS. 7a and 7b are flow diagrams of the interrupt driven data input and output from the vehicle sensors, battery system sensors and displays.

FIG. 8 is a block diagram of the energy management system interface with the vehicle navigation system.

25 FIG. 9a is a flow diagram of the energy management system interface with the navigator.

FIG. 9b is a flow diagram of the navigator interface with the energy management system.

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1 Detailed Description of the Invention

Referring to the drawings, FIG. 1 shows the relationship of the energy management system (EMS) to the various sensor inputs, controlled system outputs, driver interface and display for the vehicle. The energy management system electronic module 10 incorporates a micro-controller 12 as a calculation engine and means for controlling the various systems of the electric vehicle. In the embodiment shown in the drawings, an Intel Model 10 196KR processor is employed. The Memory systems, including a nonvolatile random access memory (NVRAM) 14 and a read only memory (ROM) 16 provide data storage for the microcontroller. As will be discussed in greater detail subsequently, data for driving profiles, vehicle status and operational models including a battery model and vehicle model are stored in the memory. Those skilled in the art will recognize that various memory configurations and combinations may be employed.

The EMS receives inputs from a variety of sensors. Battery sensors including a battery pack voltage sensor 18, a battery pack temperature sensor 20 and a battery pack current sensor 22, provide information on the battery for use by the EMS. Various vehicle sensor inputs including an inside air temperature sensor 24, an outside 25 air temperature sensor 26, a motor controller temperature sensor 28, a motor temperature sensor 30, a speed sensor 32 and accelerometer 34 and an ignition switch 36 provide data input to the EMS for the various vehicle systems. The designation "ignition switch" is used for easy 30 understanding by drivers of internal combustion engine vehicles and comprises an on-off switch enabling the operation of the electric vehicle.

The driver interface to the EMS comprises a standard accelerator pedal 38 and brake pedal 40 for direct control 35 of the vehicle. In the present embodiment, a series of four control buttons 42 are employed for control of the EMS system in response to menus displayed for the driver



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1 on a text display 44. The various control buttons and
their function and the menus associated with the EMS will
be described in greater detail subsequently.

Other displays to the driver of the electric vehicle
5 are controlled by the EMS including a standard speedometer
46, trip and continuous odometers 48, a fuel gauge 50 and
charge and reserve icons 52. The fuel gauge provides a
visual indication of charge remaining in the battery and
is again analogized for familiarity to a "fuel" gauge in
10 an internal combustion vehicle. The charge and reserve
icons inform the driver of connection of the electric
vehicle to a charger for recharging of the batteries and
operation of the battery in a reserve mode for very
limited distance travel with the battery in an essentially
15 depleted state.

The microcontroller of the EMS is interfaced with
various vehicle systems to control their operation. These
systems include the motor controller 54 which activates
the traction motor driving the electric vehicle. The
20 heating, ventilation and air-conditioning (HVAC) system 56
and external lighting system 58 of the vehicle are
controlled by the EMS based on inputs from the driver
interface and energy efficiency considerations as will be
described in greater detail subsequently. The charger 60
25 for the battery in the vehicle is controlled by the EMS to
recharge the battery when connected to a charging station.

As best seen in FIG. 2 for the present embodiment of
the system, the battery sensor inputs and charger system
are incorporated in a self-contained battery monitoring
30 module 62 which communicates with the microcontroller
through a serial port 64. Those skilled in the art will
recognize that the battery monitor circuit module could be
an integral part of the EMS itself. An electro-optical
interface employing IR LEDs 66 and IR detectors 68 is
35 employed for the battery system. Selection of the
charging algorithm to be used in charging the batteries in
the electric vehicle is accomplished by the EMS based on

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1 input from the driver on available charging time. The
microcontroller employs a selection of charging algorithms
which takes into account the battery pack history and
current state of charge to assist in extending the cycle
5 life of the battery. Battery pack replacement cost is
substantial, consequently, this aspect of the EMS provides
high-cost efficiency for the electric vehicle. The
charging algorithm is altered by the EMS based on input
from the driver identifying the amount of time the vehicle
10 will be connected to the charging site. If the vehicle is
to be unused for an extended period of time, as an
example, the EMS employs a charging algorithm to equalize
the battery pack, normally a time consuming charging cycle
important to extending battery pack life. If the charging
15 period is shorter, the charging algorithm employed by the
EMS is tailored to accomplish maximum charge within the
allotted time without degradation of the battery pack
life. Battery charging algorithms employed in the present
embodiment are exemplified in the publication by Linden,
20 David, Handbook of Batteries and Fuel Cells, McGraw-Hill,
1984, pp. 14-79 through 14-92.

State of the art motor controllers provide for
returning regenerated power to the energy storage system
of the vehicle during electrodynamic braking. In vehicles
25 with energy storage systems comprised of two or more types
of storage devices having differing rates of charge and
discharge, the EMS, through the I/O port, directs the
motor controller to select the particular energy storage
subsystem which is to receive the regenerated energy.

30 Communications with the driver are accomplished by
the microcontroller through a serial port 70 to the text
display 44 and from the driver controls through a polled
I/O port 72. The accelerator pedal 38 and brake pedal 40
as portions of the driver controls are routed through the
35 EMS which converts the inputs made by the driver to output
signals enabling the motor controller through a standard
I/O port. Control of the motor controller and brakes is



1 accomplished in a standard manner and will not be detailed
in this disclosure. The other driver controls comprise
the four control buttons 42 previously referenced. In the
embodiment shown in the drawings, these buttons comprise
5 a SCROLL key, an ENTER key, a NUMERIC key and an ESCAPE or
EXIT key. These key designations are used for easy
understanding by those familiar with common computer entry
and may employ different names in a preferred embodiment.

Output to the text display is accomplished in a menu
10 format. The menu hierarchy employed in the present
embodiment is shown in FIG. 3a and 3b. Initialization of
the system places the EMS microcontroller in the energy
management system check identified in block 310. The
initial display of the system is the main menu identified
15 in block 312. In the present embodiment, the text display
is a four line by twenty character system. Normally the
EMS system operates in a "non-expert" (NI) mode. This
mode provides simple functional response to the control
buttons operated in response to the various menus. The NI
20 mode is initiated by the driver depressing a single
control button. The functions available to the driver in
the NI mode are predict range, memorize trip, select
driving mode, display vehicle status and charge battery.
These functions are provided in separate menus identified
25 in blocks 314, 316, 318 and 320, respectively.

If the driver depresses two control buttons
simultaneously, the EMS initiates an "expert" (E) mode
which provides additional, more complex functions for
control of the system. The EXPERT MODE menu represented
30 in block 322 allows the driver to reconfigure the EMS
system by setting the time and date represented as a menu
in block 324 and change the display identified as menu
block 326 which allows a change of the language employed
by the display and the units employed (English or metric)
35 by the EMS system and displays. A CHANGE BATTERY MODEL
menu represented in block 328 allows the driver to change
the battery model or change the charging algorithm for the

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1 battery as previously described. The final menu available
in the expert mode is the MEMORIZE TRIP menu identified in
block 330 which allows the EMS to memorize the energy
consumption of a frequently employed driving path for the
5 vehicle.

The various menus of the system are selected by
pushing the SCROLL button until the function of choice
appears followed by pushing the ENTER button. Once a menu
is selected, the various functions of the menu are
10 selected employing the SCROLL button followed by pressing
the ENTER button at the desired function to confirm the
selection. For various functions, an option is provided
to the driver in the form of a numeric value which may be
increased through set steps in a wrap-around fashion by
15 pressing the NUMERIC button. The ESCAPE key is provided
for the driver to reverse menu selection to return to the
next higher menu level. The functions of the EMS as
selected from the menus will now be described.

The PREDICT RANGE menu when selected provides a
20 series of choices: "level ground at xx mph," "stop and
go," "constant speed uphill at xx mph," "constant speed
downhill at xx mph," "constant speed up and down at xx
mph" and any one of up to nine memorized trips. The
program format of this menu is shown in Table 1. The
25 driver uses the scroll button to select the type of
driving profile which he desires. Once the proper profile
is displayed, he pushes the enter button to confirm the
selection. As an example, if the driver chooses "stop and
go" the EMS employs the vehicle model from the ROM with
30 the driving profile for "stop and go" conditions from the
NVRAM. The stop and go conditions data employed in the
present system is represented by the Simplified Federal
Urban Driving Cycle (SFUDS), a copy of which is provided
in Table 2. The format of the data required by the EMS to
35 calculate range from either power as a function of time or
velocity as a function of time follow that of the SFUDS
cycle shown in the listing provided in Talbe 2. This

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1 driving cycle is represented by a series of vehicle
velocities at one second intervals over a driving time of
six minutes. From this information, the vehicle model
calculates the power required at each step and subtracts
5 the energy used at each step from that available in the
battery pack as calculated using the battery model from
the ROM assuming and initial state defined to the
micro-controller of the EMS through the serial port from
the battery monitor module. The EMS continues to run the
10 stop and go steps repeating the six minute cycle
consecutively until the calculated energy remaining in the
battery pack would no longer be able to provide the power
for the next step. The distance covered at each step is
accumulated and the reported range is that covered at the
15 last successful step. This information is reported to the
driver on the display as "range under stop and go
conditions is xxx miles."

If the driver selects from the PREDICT RANGE menu,
any of the other choices, with the exception of the
20 memorized trip, the speed parameter must be entered by the
driver to allow the EMS to make a range prediction. For
example, if the driver has selected on the menu "constant
speed downhill at xx mph," the numeric key is pressed by
the driver to change the desired speed. In the present
25 embodiment as identified in the programming application of
Table 1, a minimum speed of 20mph and a maximum speed of
80 mph is employed. The initial speed displayed in the
menu may start with a default value e.g., 30 mph, or the
last speed value employed by a selection on the EMS.
30 Pressing the numeric button would increment the speed by,
for example, five miles per hour for each button push to
the maximum programmable speed at which time the input
wraps to the lowest speed e.g., 20mph. When the driver
obtains the speed desired on display, the enter button is
35 pressed and the EMS then employs the vehicle model to
predict the range. In this case, the power calculation is
based on a constant condition which is derived from a

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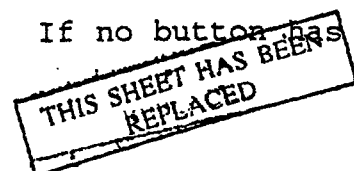
- 1 matrix of power required for the given profile and speed selected.

The battery model and vehicle model employed in the present system are based on the electric vehicle battery performance application program DIANE disclosed in the paper entitled: Users Guide to DIANE Version 2.1: A Micro Computer Software Package for Modeling Battery Performance in Electric Vehicle Applications, by W. W. Marr, W. J. Walsh and P. C. Symons, June 1990, published by the Energy Systems Division of the Argon National Laboratory. The vehicle model provided in Appendix A of the paper as modified for the present system is disclosed in Appendix A to this application. Data employed in the battery model by the present embodiment are included as Appendix B to this application. The result of the calculation by the EMS based on the vehicle model for the selected profile is displayed as, for example, "range under constant speed of xx mph downhill is xxx miles."

If the driver selects from the PREDICT RANGE menu, one of the memorized trips, the calculation made by the EMS employs the stored table of energy consumption versus time as input to the vehicle mathematical model. After calculation, the resulting display based on the existing battery charge would be "trip number x can be successfully completed z times with yyy miles remaining." This format allows use of the EMS system for a standard commute allowing the driver flexibility in selecting charging times for the vehicle.

A flow diagram of exemplary programming for operation of the EMS in the PREDICT RANGE menu is shown in FIGS. 4a and 4b. Data formats for this program sequence are shown in the listing provided in Table 1. The EMS displays the PREDICT RANGE menu on the text display as shown in box 410 for review by the driver. The EMS microcontroller monitors the driver interface control buttons to determine if a control button has been pressed within ten seconds as shown by the decision block 412. If no button has been

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1 pressed, the EMS sets the mode of operation to the
non-expert (NI) mode for operation in block 413, blanks
the display 414, and enters a wait routine for 416 for
button sensing. Returning to the decision block 412 if a
5 button has been pressed, the microcontroller determines if
the ESCAPE key has been pressed, block 418. If so, the
program returns to block 412, setting the system to the NI
mode. If the ESCAPE key is not the key pressed, the
microcontroller determines if the SCROLL key has been
10 pressed in block 420. If the SCROLL key has been
depressed, the microcontroller moves to display the next
menu as identified in block 510. If the SCROLL key has
not been depressed, the EMS determines if the NUMERIC key
has been depressed in block 424. The NUMERIC key has no
15 significance in this menu pattern and if the numeric key
has been depressed, control is returned to block 412 as if
no button had been pressed. If the button pressed is the
ENTER key, by default the program proceeds to block 426
and sets the parameters i and j=0. The microcontroller
20 then displays the scrolled menus identified in Table 1 in
the form of menu (1,i) and appends the speed and units or
the trip number as shown in block 428. For example, if
the menu pointer is at menu(1,2) the display will show
"uphill at xx mph." If, however, the menu pointer is at
25 menu(1,5) the display will show "memorize trip # x."
After displaying the menu, the controller enters decision
block 430. If the second index of the menu pointer equals
one, the microcontroller proceeds to decision block 432 to
await a button press. If no button is pressed within ten
30 seconds, the microcontroller returns to entry point A at
block 413. If a button has been pressed, the
microcontroller determines if the SCROLL key is pressed in
decision block 434. If the SCROLL key has been depressed,
the second index of the menu pointer i is incremented in
35 block 436 with a counter operating modulo 7. The counting
modulus, length (x), for the various counters described
are shown in Table 1. Upon incrementing of the menu

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1 index, the program returns to entry point B at block 428
to display the new menu. If the SCROLL key was not the
button pressed, the microcontroller continues to decision
block 437 to determine if the ENTER key was pressed. If
5 the ENTER key was pressed, selecting the menu having
pointer equal 1, the driver has selected the "stop and go"
menu. In this case, the microcontroller retrieves from
memory the vehicle model and employs the SFUDS data as a
driving profile to determine vehicle range as shown in
10 block 438. Upon completion of the calculation, a display
of "stop and go range is" accompanied by the result of the
calculation and the appropriate units as shown in block
440. If no further button is pressed within ten seconds,
the program returns to entry point A as shown in block
15 442. If after the display of the stop and go answer the
ESCAPE key is pressed as detected in block 444, the
program returns to entry point B at block 428 to display
the previous menu.

If the ENTER key was not pressed, in block 436, the
20 program determines if the ESCAPE key was pressed in block
445. If the ESCAPE key was not pressed, the only key
remaining is the NUMERIC key which has no meaning for the
menu pointer of 1 since no numeric input is required by
the driver. Consequently, control is returned to block
25 432 to await an additional button press. If the ESCAPE
key has been pressed, the menu pointer is reset to 0 and
control of the program returns to entry point C.

Returning to block 430, if the second index of the
menu pointer is 0, 2, 3, or 4, additional entry for the
30 speed desired is required by the driver. Consequently,
the microcontroller waits for a button push as identified
in block 446. If a button push does not occur within ten
seconds, control of the program returns to entry point A.
If a button is pushed within ten seconds, the controller
35 determines in block 448 if the SCROLL key has been pressed
and if so, increments the menu pointer in block 450 and
returns to entry point B to display the next menu. If the

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1 SCROLL key is not pressed, the controller determines if
the ENTER key has been pressed in block 452. If the ENTER
key has been pressed, the vehicle model is run using the
matrix data for required power at the speed initially
5 displayed in the menu as shown in block 454. Upon
completion of the calculation, the selected driving
profile and the range associated with that profile is
displayed as shown in block 456. For example, if the menu
pointer was 0 providing the menu selection "level at xx
10 mph" the display will show "level at xx mph range is yy
miles."

 If the ENTER key was not depressed, the
microcontroller determines if the ESCAPE key was pressed
in block 458. If the ESCAPE key was pressed, the menu
15 pointer is reset to 0 and the program returns to entry
point C.

 If the ESCAPE key was not pressed by default, the
pressed key was the NUMERIC key resulting in incrementing
of the numeric speed value as shown in block 460. The
20 program then returns to entry point B and the display for
the given menu pointer is again provided with the
incremented speed value.

 Returning to block 430, if the second index of the
menu pointer equals 5 signifying selection of a memorized
25 trip, the program transitions to entry point D of FIG. 4b.
The microcontroller determines if a button has been
pressed in block 462 and if no button is pressed within
sixty seconds, the program returns to entry point A. If
a button has been pressed, the microcontroller determines
30 in block 464 if the ESCAPE key was pressed. If the ESCAPE
key was pressed, program control returns to entry point C.
If not, the program determines in block 466 if the NUMERIC
key was pressed. If the NUMERIC key was pressed, the
memorized trip variable j is incremented as shown in block
35 468. Incrementing of j is accomplished with a counting
modulus "memorized trips" equal to the number of segmented

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1 memory locations provided for memorizing trip data.
Control of the program then returns to entry point B.

If the microcontroller determines that the ENTER key has been pressed in block 470, the identified, memorized
5 trip present on the display screen has been selected by the driver and the microcontroller calculates the power required for the identified trip as shown in block 472. Upon completion of the calculation, the microcontroller displays the results of the calculation in the format
10 "memorized trip number j range is yy trips plus xx miles" as shown in block 474. Control of the program then returns to entry point D allowing additional calculation of memorized trip information.

Returning to decision block 430, if the second index
15 of the menu pointer equals 6, the EMS performs a data exchange and interaction with a navigator system in block 476 to provide predictions of energy availability in the battery system for routes defined by the navigator. Further description of the navigator system interaction is
20 provided in detail subsequently.

The SELECT DRIVING MODE menu allows the driver to select either a "economy," or "performance" mode for the EMS in operation of the vehicle. Normally during driving, the driver is not interacting with the EMS and therefore
25 the display is blank so as not to distract the driver. The EMS is continually monitoring various inputs from the vehicle as previously described. Inefficient energy usage by vehicle systems monitored by the EMS can be detected. As an example, if the microcontroller of the EMS receives
30 an input from the external temperature sensor indicating high outside temperature and an indication from the window position sensor that the windows are rolled down, operation of the air conditioner in attempting to cool the vehicle would be inefficient. In a direct control format
35 as shown in the drawings for the present embodiment, the HVAC system controlled by the EMS through the I/O port could be disabled until the windows are closed. In

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1 addition, (or alternatively) the EMS may display to the driver, a message "roll up windows."

In the embodiment shown in the drawings, external analog sensors, such as the temperature sensors and
5 accelerometer, are provided to the microprocessor through a multiplexed Analog to Digital input port 74 as shown in FIG. 2. Standard controls for the HVAC and motor controller as exemplary are provided through standard I/O ports 76.

10 Selection of the "performance" mode from the driving mode menu suppresses the EMS monitoring of efficiency information and precludes display of energy efficient messages to the driver. As previously described,
15 selections in the SELECT DRIVING MODE menu are accomplished by pushing the ENTER button followed by depressing the SCROLL button for selection between the sub-menu items of "economy," or "performance" followed by pushing the ENTER button to confirm the selection. In the
20 embodiment of the present invention, the default driving mode is "economy."

FIGS. 5a and 5b are a flow diagram of programming associated with the SELECT DRIVING MODE menu. The SELECT DRIVING MODE menu is displayed on the text display by the
25 microcontroller as shown in block 510. The microcontroller determines if a button has been pressed as shown in decision block 512. If no button is pressed within ten seconds, the microcontroller places the system in the nonexpert mode, blanks the display and waits for a button press as previously described with respect to FIG.
30 4a. Similarly, if the microcontroller determines in block 514 that the ESCAPE key has been pressed, exiting the SELECT DRIVING MODE menu, the microcontroller will return to its initial state.

If the SCROLL button has been pressed as shown in
35 block 516, the next menu DISPLAY VEHICLE STATUS will be displayed as shown in block 518. If the NUMERIC key is depressed as shown in block 520, the input is ignored

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1 since the NUMERIC key has no meaning at this menu level.
If by default the ENTER key has been depressed confirming
the "select driving mode" decision by the driver, the
second index of the memory pointer is set to 0 as shown in
5 block 522 and the microcontroller displays the sub-menu as
shown in block 524. The displays of the sub-menu
identified for the menu pointer having a first index 2 are
shown in Table 2.

The microcontroller again senses a button push as
10 shown in block 526 and determines if the button pressed is
the SCROLL button as shown in block 528. If the SCROLL
button has been depressed, the menu pointer is incremented
as shown in block 530 and the new sub-menu is displayed by
return through entry point X.

15 If the SCROLL key was not depressed, the
microcontroller determines if the ENTER key was depressed
in block 530. Depressing the ENTER key confirms the
selection by the driver of the displayed sub-menu and, as
shown in block 534, if the second index of the menu
20 pointer equals 0, the microcontroller establishes the
driving mode as "economy" defined in block 536. While if
the second index of the menu pointer equals 1, the
microcontroller sets the driving mode to "performance" as
shown in block 538. If the ESCAPE key has been depressed
25 as shown in block 540, the second index of the menu
pointer is reset to 0 and the program returns to entry
point X.

The DISPLAY VEHICLE STATUS menu allows the driver to
examine the status of the data inputs and outputs of the
30 EMS. For example, selecting the DISPLAY VEHICLE STATUS by
pressing the ENTER button would allow a display of inside
air temperature, outside air temperature, motor
temperature, battery pack temperature, controller
temperature, instantaneous battery pack voltage,
35 instantaneous battery pack current draw and any values
calculated by the EMS from these parameters. With the
limited display size in the present embodiment, the

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1 DISPLAY VEHICLE STATUS selection provides sub-menus with
one or more of the displayed values, e.g. "outside air
temperature is xx." Sequential display of the various
status items is accomplished by pressing the SCROLL
5 button.

The CHARGE BATTERY menu allows the driver to inform
the EMS of the desired charging time to allow optimum
charging of the battery by the EMS for that time. For
example, if the driver is running into the store for
10 groceries and the vehicle is attached to a charging
station at the store, the vehicle will only be on charge
for a few minutes. If on the other hand, the driver has
parked the vehicle in his home garage, it may be left for
a number of hours. Slow charging is easier on the battery
15 pack than fast charging. Consequently, the EMS would
direct different charging algorithms to be used depending
upon the length of time available to charge. Invoking the
CHARGE BATTERY function from the main menu by pushing
ENTER causes a prompt of "charge battery for xx hours" to
20 appear. The driver can modify the numeric value by
pressing the NUMERIC button as described previously. The
ENTER button is then pressed to establish the time
available for charging to the EMS. The EMS then selects
an appropriate algorithm based on predetermined hour
25 values and proceeds to charge the vehicle. In the present
embodiment, if a particular time is not established by the
driver through the use of this function, the EMS will
employ an algorithm based upon the optimum charging
efficiency for the present state of the battery.

30 As shown in FIG. 3a, subsequent to establishing the
charging procedure through the CHARGE BATTERY menu, the
EMS provides a VEHICLE ON CHARGE menu 332 for providing
information on the battery charging status. In addition,
upon completing the battery charging cycle, a CHARGE
35 COMPLETED menu 334 is provided for notification of the
driver of a charge and battery status prior to reentering
the MAIN DISPLAY menu.

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1 As previously described, the expert menu functions
entered through the EXPERT menu 322 allow modification and
control of the EMS by the driver. The SET TIME menu is
self explanatory and allows the driver to update the EMS
5 system with current time and date. The CHANGE DISPLAY
menu allows sub-menus of SELECT LANGUAGE and SELECT UNITS.
The SELECT LANGUAGE menu in the E mode causes a series of
languages to appear one at a time on the display. The
driver selects the desired language for use on the EMS
10 displays by pressing the SCROLL button and confirming the
choice with the ENTER button. The information on language
choice is saved in the NVRAM and the chosen language is
used until changed by an alternate selection using the
CHANGE DISPLAY menu. All messages described in the
15 various menu functions are encoded in all languages
available. These messages are stored in the
microcontroller ROM. The SELECT UNITS function of the
change display menu operates in the same manner as the
SELECT LANGUAGE function to allow selection of English or
20 metric units for display. For example, selection of the
English system will display miles and miles per hour,
while the metric display will display kilometers and
kilometers per hour.

 The CHANGE BATTERY MODEL and CHANGE CHARGING
25 ALGORITHM functions are provided to allow modification of
the numeric parameters for changes of battery types, aging
of the batteries and other altered operating parameters
for the vehicle.

 The final menu provided in the E mode is the MEMORIZE
30 TRIP menu. This function is selected by the driver to
memorize the energy consumption of a particular trip which
will be accomplished on a repetitive basis to allow
prediction by the EMS for successfully accomplishing that
trip with existing battery charge. Upon selection of the
35 memory function, the display shows "memorize trip number
x." If the driver now pushes the ENTER button, the EMS
will ask for an indication of when to start memorizing



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1 battery power consumption data. This is accomplished by
displaying "memorizing trip number x" and, on the next
line of the display, "start" indicating that the next
depression of the ENTER button will cause the EMS to begin
5 memorizing energy consumption. During memorization, the
power drain by the vehicle is sampled periodically (in the
present embodiment, once per second). This power
requirement is saved in a table along with the amount of
time this amount of power was required. The power is
10 determined by monitoring the battery pack current and
voltage and calculating a product of the instantaneous
values. Once the enter button is pushed and the
memorization is in progress, the word "start" is replaced
on the display by the word "stop" indicating that a
15 subsequent push of the ENTER button will cause the
memorization to stop. A variation on this process is
accomplished if the trip number x has already been
memorized. If the driver selected that trip number, the
EMS assumes that the driver wishes to replace the
20 information previously memorized by information for a new
trip. In this case, the display shows "replacing trip
number x" along with the start or stop indications. In
the present embodiment, up to nine trips can be memorized.
Whenever a trip is memorized, the resulting data table of
25 energy consumption allows range prediction without
requiring calculation based on the vehicle model. Since
the energy consumption for the trip is already known,
prediction is accomplished by subtracting the energy
consumption from the available energy in the battery pack
30 for each time step of the table. The tabular information
for the memorized trips is stored in the NVRAM.
Limitations on the number of stored trips is imposed by
memory size.

Details of the overhead for the operating system of
35 the microcontroller in the present invention are shown in
FIGS. 6a and b and 7a-e. The microcontroller for the
present embodiment initiates operation with a system reset

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1 610 as shown in FIG. 6a. Interrupts are disabled 612
while initialization of the input output ports 614 is
accomplished. As previously described with respect to
FIG. 2, the I/O ports 76 provide the data paths for
5 communication between the microcontroller and the ignition
switch, instrument panel 45 (comprising the various
display elements including the speedometer, odometers,
fuel gauge and charge and reserve icons), the HVAC
controller and the motor controller.

10 After initialization of the I/O ports, the serial
port interrupt (PTS) is enabled for communication through
serial port 64 and of FIG. 2. The microcontroller
communicates with the battery monitor module through the
serial port providing a "cancel charge packet" data block
15 to the self contained battery monitor module as a reset.
See block 618. The microcontroller then blanks the text
display through serial port 70 and the instrument panel
through the I/O ports. See block 620.

The microcontroller next enables the software timer
20 interrupts 622 to allow interface with the clock circuit
78 of FIG. 2 for generalized program clocking. The speed
sensor interrupt is enabled 624 for communication with the
speed sensor. In the present embodiment, the speed sensor
comprises a slotted wheel 80 shown in FIG. 2 located on a
25 drive axle of the vehicle, an IR light emitting diode 82
providing an illumination source through fiber optic cable
to one side of the slotted wheel and an IR detector 84
connected through fiberoptic cable receiving signal from
the opposite side of the slotted wheel. The signal from
30 the IR detector, representative of the rotational speed of
the axle, is provided to an interrupt port 86 in the
microcontroller.

The microcontroller enables the speed calculation
interrupt 626 as a final preoperation function.

35 The microcontroller senses the status of the vehicle
ignition switch in decision block 628. If the switch is
not "on" indicating desire for operation of the vehicle by

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1 the driver (or turning off of the ignition switch since
the last calculation cycle) the microcontroller continues
to blank the instrument panel and EMS text display as
shown in block 630. Upon sensing that the ignition switch
5 has been turned on, the microcontroller determines in
block 632 if the ignition switch was previously "off". If
the ignition switch was previously "off", the
microcontroller performs an instrument panel and EMS
startup display 634 and performs a system check 636 to
10 detect hardware faults. If no fault is detected in block
638, the microcontroller sets the text display to the main
menu previously described with respect to FIG. 3 in block
640. If a system fault was detected, the fault is
reported 642 by appropriate annotation of the text
15 display.

Upon completion of the startup sequence, or if the
ignition switch was not previously "off", the
microcontroller displays the instrument panel and EMS
information 644 corresponding to the various sensor
20 inputs. The microcontroller monitors the control buttons
to determine if a button has been pressed 646 and if the
SCROLL button has been pressed, highlights the action
following the presently highlighted action on the menu 648
to scroll through the menus as previously described with
25 respect to FIGS. 3, 4, and 5. If the ENTER key has been
pressed, the microprocessor performs the highlighted
action and designates the appropriate menu for the
highlighted action as active 650, also previously
described with respect to FIGS. 3, 4 and 5. If the
30 NUMERIC key has been pressed, the microprocessor
determines if a numeric variable is highlighted in the
menu 652. If no numeric variable is highlighted,
depressing the NUMERIC key has no function. A system
check for faults is accomplished 654 and if a system fault
35 is detected 656, the system reports the fault 658, program
control then returns to block 628.

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1 If a numeric variable is highlighted in block 652 and the NUMERIC key is pressed, the highlighted numeric variable is incremented by the count modulus 660 as previously described with respect to FIGS. 4 and 5.

5 If the ESCAPE key is pressed, the microprocessor sets the active menu to the menu above the present active menu on the menu hierarchy list in block 662 as previously described with respect to FIGS. 3, 4 and 5.

10 If the SCROLL and ENTER keys are depressed simultaneously, the microcontroller sets the active menu as the EXPERT MODE menu as shown in block 664 and previously described with respect to FIG. 3.

15 All other functions of the microcontroller are initiated through the interrupt processor on a timed or demand basis. Exemplary interrupt routines for the microcontroller are shown in FIG. 7. The software timer update interrupt routine occurs periodically as shown in FIG. 7a. Upon receiving this interrupt, the microcontroller determines if the speed sensor needs to be enabled in block 710. The speed sensor interrupt is disabled in various other interrupt routines as will be described subsequently. If the speed sensor interrupt has been disabled, the microcontroller enables the PTS speed sensor interrupt 712 and enables the speed calculation interrupt 714 to allow normal processing of speed information for update of the display on the instrument panel speedometer and odometers.

20 The microcontroller next conducts the Analog to Digital conversion of analog sensor data input in block 716. Results of the sensor inputs are stored in memory block 718 to update the VEHICLE SYSTEM STATUS menu for display upon demand as described with respect to FIG. 3. Updated information is output to the instrument panel displays by the microcontroller in block 720. The microcontroller then returns to the interrupt wait state.

35 Calculation of vehicle speed and distance traveled for display on the speedometer and odometers of the

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1 instrument panel is accomplished employing interrupt
routines for speed calculation and the speed sensor PTS
interrupt as shown in FIGS. 7b and 7c. In the present
embodiment, interrupt signals received from the IR
5 detector of the speed sensor are accumulated and timed
based on a predetermined PTS count. As shown in FIG. 7b,
upon receiving an interrupt from the IR detector, the
microcontroller decrements the PTS count 722 and
determines if the PTS count is now 0 in block 724. If the
10 PTS count is 0, the PTS interrupt is disabled 726 to allow
a time speed calculation to occur in response to a speed
calculation interrupt. The time of the PTS interrupt from
the speed sensor is recorded 728 and stored for speed
calculation. A return is then executed from the interrupt
15 handler.

Speed calculation is accomplished upon receiving a
speed calculation interrupt as shown in FIG. 7c. Speed
calculation is accomplished by determination of the total
elapsed time for the PTS count cycle of the speed sensor
20 interrupts from the recorded time intervals in block 730.
The total odometer and trip odometer are updated in block
732 and 734 respectively and the PTS count is reset in
block 736 for initializing the speed sensor interrupt.
The speed calculation interrupt is disabled 738 to
25 preclude a speed calculation interrupt prior to
initialization of the speed sensor PTS interrupts through
the software timer update interrupt routine as previously
described. A return from the interrupt handler is then
executed.

30 Data from the battery monitor module is received on
the serial port as previously described. Incoming data is
accepted through a serial port receive interrupt as
described in FIG. 7d. Data transmitted from the battery
monitor module is provided in a predefined format for
35 verification of valid data which is accomplished in block
740. If the data received is not valid as determined in
block 742, a tabulation of the number of errors is

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1 incremented in block 744. If the number of errors
detected is less than 10, as determined in block 746, the
error is ignored and a return is executed from the
interrupt handler. If the number of errors has reached
5 10, the microcontroller reports the error through the EMS
text display as shown in block 748 to notify the driver of
a battery monitor module failure.

If valid data is received from the battery monitor
module, a new "fuel" status is calculated in block 750 to
10 determine power remaining in the battery. Parameters for
the battery model are then updated in block 752 for use in
vehicle model calculations as previously described. The
error monitor flag is then reset to 0 in block 754. A
determination is made in block 756 if an updated message
15 to the EMS display is required. For example, if the menu
on the display is the vehicle on charge menu as previously
described with respect to FIG. 3, a change in the battery
status would be reflected on the menu. The
microcontroller alters the display message as shown in
20 block 758, if required, and the interrupt handler is reset
in block 760 for return to the wait mode.

The software timer clock interrupt is accomplished as
shown in FIG. 7e to accomplish updating of the system
clock 762 and transfer of any battery management system
25 data to the battery monitor module through the serial
port. As previously described, the battery monitor module
in the present embodiment is a self-contained unit,
consequently, data is provided in a packet format executed
by the microcontroller as shown in block 764. An example
30 of data transmissions of this type would be associated
with charging of the battery wherein control of the
charging current and voltage by the battery monitor module
is accomplished to charge the battery according to the
desired charging algorithm as previously described.

35 Upon completion of the software timer clock
interrupt, the microcontroller returns to the wait state
from the interrupt handler.

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1 The EMS in combination with a vehicle navigator
system provides further expanded capability for efficient
operation of the electric vehicle. Navigator systems,
such as those disclosed in U.S. Patent No. 4,926,336 to
5 Yamada provide a database typically including street
names, street segment x and y coordinates, street segment
end addresses and assumed street segment speeds for a
given mapped area. The basic purpose of a navigator is to
provide an optimum route to be driven based on a starting
10 point and a destination point. The present embodiment
adds to the navigator database street segment grade and
direction of grade, stop sign and traffic light locations
and location of charging stations for electric vehicles.
Associated with the traffic light data is a probability of
15 a green light for each direction of traffic in the control
intersection. Dynamic information on traffic congestion
for given street segments is provided through a radio
interface.

FIG. 8 provides a basic block diagram of the
20 interface between the navigator and EMS. The navigator
810 is a self-contained system employing a database 812
having the characteristics previously described and a
radio interface 814. The navigator incorporates a
calculation engine 816 for determining routes between an
25 entered beginning point and a desired destination point.
A standard serial port interface 818 employing RS232 or
other standard communication protocol connects the
navigator to the EMS. A third serial port 88 as shown in
FIG. 2 is employed by the microcontroller for
30 communication with the navigation system.

In operation, the driver provides present position
and destination information to the navigator system. The
navigator selects several time efficient routes using
normal processing models, as described in the prior art.
35 These routes are likely to be the most energy efficient,
however, iteration between the navigator and EMS is
required for optimizing energy efficiency of the route.

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1 The data information for the route selected by the
navigator is communicated to the EMS over the serial link.
A protocol of the present embodiment provides for
transmission of each street segment in following format:
5 Send start of segment character (e.g., "S"); send length
of segment (e.g., xx miles); send indication of stop at
start of segment (e.g., "X"); send grade of segment (e.g.,
xx%); send direction of grade (e.g., "U" or "D" for up or
down); send nominal speed of segment (e.g., xx
10 miles/hour); and, send end of message character (e.g.,
"E"). The energy usage for the individual segment is
calculated by the EMS employing the vehicle model and
standard prediction algorithms previously described. For
example, if the segment is an upward grade, with an
15 average speed of 30 mph, the processing algorithm for the
"uphill at xx mph" previously described with regard to the
predict range menu is employed. A start or stop on the
segment is accommodated by the EMS through a calculation
scheme defining a predetermined acceleration or
20 deceleration based on the nominal speed of the segment.
For example, if the average speed of the segment is low,
acceleration of .1 g is employed, while if average speed
of the segment is high, an acceleration of .25 g is
employed. Stopping at a constant deceleration of .5 g is
25 employed.

The EMS will calculate the energy consumption as
watt-hours for the entire trip defined by the navigator
segment by segment. If the trip can be made on the energy
available in the battery pack, the EMS reports the energy
30 consumption for the trip. The navigator and EMS iterate
with regard to the other candidate routes for optimizing
the energy usage.

If the energy required for the trip will exceed the
available battery energy, the EMS identifies to the
35 navigator the street segment indicating where the vehicle
will "run out" of energy. The navigator will then employ
an alternate route scheme for identifying a destination

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1 with a charging station with a lower mileage requirement
than the energy exhaustion point. Calculation of the
route to the charging station with verification by
iteration of the route with the EMS for energy consumption
5 calculation is accomplished. Calculation of a route from
the charging station to the original destination is then
accomplished by the navigator. Calculation of this route
requires input by the driver for the charging time to be
employed at the charging station. Calculation of the
10 energy level in the battery after the proposed charging is
accomplished using the battery model as previously
described.

Operation of the EMS in the "performance" mode allows
elimination of iteration on the routes selected by the
15 navigator and the most time efficient route selected by
the navigator is employed for calculation of capability
for the vehicle to accomplish the route on the given
energy charge in the battery.

FIGs. 9a and 9b are flow diagrams describing the
20 hand-shake operation between the EMS and navigator systems
in the electric vehicle. As shown in FIG. 9a, upon entry
by the driver of a present position and destination point,
the navigator establishes a candidate route as shown in
block 910. The navigator sends a ready-to-transmit signal
25 to the EMS 912 which is received by the EMS in block 914
of FIG. 9b. The EMS responds by sending a ready-to-
receive signal 916 which is received by the navigator in
block 918 of FIG. 9a. The navigator proceeds to send
route information 920 on a segment-by-segment basis to the
30 EMS which receives the route information 922 and runs the
vehicle model 924 to establish energy usage. The EMS
determines if sufficient energy is remaining to complete
the route proposed by the navigator. If sufficient energy
remains an energy consumed value is provided to the
35 navigator in block 928 which is received as a response by
the navigator in block 930. If sufficient energy does not
remain in the battery pack, the EMS provides a pointer to

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1 the last successful route segment 932 provided as the
response to the navigator. Upon completion of the
interaction between the EMS and the navigator, the EMS
returns to standard EMS functions 934. The information
5 concerning energy consumption or pointer for last
successful route segment received by the navigator is
analyzed in block 936. If sufficient energy is available
for the route, additional candidate routes are evaluated
and a selection of the most energy efficient route is made
10 by the navigator software in block 938. If insufficient
energy is available for any of the chosen routes, the
navigator establishes a route to a charger station nearest
the last successful route segment and employing the
charger location as an initial position calculates routes
15 to the desired destination based on driver input as to
charging time in block 940. The final route is then
communicated to the driver by the navigator in block 942.

Table 1

Coded into the program:

20 min speed = 20
max speed = 80

menu (1,0) = "LEVEL AT"	menu (2,0) = "ECONOMY"
(1,1) = "STOP AND GO"	(2,1) = "PERFORMANCE"
(1,2) = "UP HILL AT"	
(1,3) = "DOWN HILL AT"	
25 (1,4) = "UP AND DOWN AT"	
(1,5) = "MEMORIZE TRIP #"	
(1,6) = "NAVIGATOR PREDICTION"	

length (1) = 7
(3) = 1

30 Set by default or previous driver interaction:

Speed = 30
Units = "MPH"
Memorized trips = 3

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TABLE 2

Simplified FUDS (SFUDS) with velocity slightly changed
 cycle time including rest, (s), TC= 360
 rest time at end of cycle, (s), TREST = 0
 s-by-s velocity, (km/h), for TC-TREST s

5	.000000E+00	.000000E+00	.000000E+00	.000000E+00	.000000E+00
	.000000E+00	.000000E+00	.000000E+00	.000000E+00	.000000E+00
	.000000E+00	.000000E+00	.000000E+00	.000000E+00	.000000E+00
	.000000E+00	.240000E+01	.480000E+01	.720000E+01	.970000E+01
	.111000E+02	.122000E+02	.134000E+02	.146000E+02	.158000E+02
	.169000E+02	.179000E+02	.187000E+02	.195000E+02	.201000E+02
10	.208000E+02	.214000E+02	.220000E+02	.227000E+02	.233000E+02
	.240000E+02	.245000E+02	.249000E+02	.256000E+02	.261000E+02
	.275000E+02	.290000E+02	.303000E+02	.315000E+02	.328000E+02
	.340000E+02	.351000E+02	.360000E+02	.370000E+02	.378000E+02
	.388000E+02	.396000E+02	.378000E+02	.359000E+02	.341000E+02
	.320000E+02	.301000E+02	.277000E+02	.253000E+02	.227000E+02
15	.171000E+02	.114000E+02	.580000E+01	.200000E+00	.000000E+00
	.000000E+00	.000000E+00	.000000E+00	.000000E+00	.000000E+00
	.000000E+00	.000000E+00	.000000E+00	.000000E+00	.000000E+00
	.000000E+00	.240000E+01	.480000E+01	.720000E+01	.970000E+01
	.111000E+02	.122000E+02	.134000E+02	.146000E+02	.158000E+02
	.169000E+02	.179000E+02	.187000E+02	.195000E+02	.201000E+02
20	.208000E+02	.214000E+02	.220000E+02	.227000E+02	.233000E+02
	.240000E+02	.245000E+02	.249000E+02	.256000E+02	.261000E+02
	.275000E+02	.290000E+02	.303000E+02	.315000E+02	.328000E+02
	.340000E+02	.351000E+02	.360000E+02	.370000E+02	.378000E+02
	.388000E+02	.396000E+02	.378000E+02	.359000E+02	.341000E+02
	.320000E+02	.301000E+02	.277000E+02	.253000E+02	.227000E+02
	.171000E+02	.114000E+02	.580000E+01	.200000E+00	.000000E+00
25	.000000E+00	.000000E+00	.000000E+00	.000000E+00	.000000E+00
	.000000E+00	.000000E+00	.000000E+00	.000000E+00	.000000E+00
	.000000E+00	.240000E+01	.480000E+01	.720000E+01	.970000E+01
	.111000E+02	.122000E+02	.134000E+02	.146000E+02	.158000E+02
	.169000E+02	.179000E+02	.187000E+02	.195000E+02	.201000E+02
	.208000E+02	.214000E+02	.220000E+02	.227000E+02	.233000E+02
30	.240000E+02	.245000E+02	.249000E+02	.256000E+02	.261000E+02
	.275000E+02	.290000E+02	.303000E+02	.315000E+02	.328000E+02
	.340000E+02	.351000E+02	.360000E+02	.370000E+02	.378000E+02
	.388000E+02	.396000E+02	.378000E+02	.359000E+02	.341000E+02
	.320000E+02	.301000E+02	.277000E+02	.253000E+02	.227000E+02
	.171000E+02	.114000E+02	.580000E+01	.200000E+00	.000000E+00
35	.000000E+00	.000000E+00	.000000E+00	.000000E+00	.000000E+00
	.000000E+00	.000000E+00	.000000E+00	.000000E+00	.000000E+00
	.000000E+00	.240000E+01	.480000E+01	.720000E+01	.970000E+01
	.111000E+02	.122000E+02	.134000E+02	.146000E+02	.158000E+02

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1	.169000E+02	.179000E+02	.187000E+02	.195000E+02	.201000E+02
	.208000E+02	.214000E+02	.220000E+02	.227000E+02	.233000E+02
	.240000E+02	.245000E+02	.249000E+02	.256000E+02	.261000E+02
	.266000E+02	.270000E+02	.274000E+02	.278000E+02	.283000E+02
	.288000E+02	.293000E+02	.296000E+02	.301000E+02	.304000E+02
5	.309000E+02	.312000E+02	.362000E+02	.407000E+02	.447000E+02
	.483000E+02	.513000E+02	.543000E+02	.571000E+02	.597000E+02
	.621000E+02	.644000E+02	.666000E+02	.681000E+02	.695000E+02
	.708000E+02	.721000E+02	.732000E+02	.744000E+02	.755000E+02
	.766000E+02	.777000E+02	.787000E+02	.797000E+02	.806000E+02
	.814000E+02	.824000E+02	.832000E+02	.840000E+02	.848000E+02
10	.855000E+02	.863000E+02	.869000E+02	.875000E+02	.861000E+02
	.847000E+02	.832000E+02	.818000E+02	.803000E+02	.789000E+02
	.774000E+02	.760000E+02	.745000E+02	.731000E+02	.718000E+02
	.703000E+02	.689000E+02	.676000E+02	.663000E+02	.649000E+02
	.650000E+02	.653000E+02	.655000E+02	.657000E+02	.660000E+02
	.661000E+02	.663000E+02	.665000E+02	.668000E+02	.669000E+02
15	.671000E+02	.673000E+02	.674000E+02	.676000E+02	.678000E+02
	.679000E+02	.681000E+02	.682000E+02	.684000E+02	.686000E+02
	.687000E+02	.689000E+02	.689000E+02	.690000E+02	.692000E+02
	.694000E+02	.695000E+02	.695000E+02	.697000E+02	.698000E+02
	.698000E+02	.700000E+02	.687000E+02	.673000E+02	.660000E+02
	.645000E+02	.632000E+02	.618000E+02	.604000E+02	.591000E+02
	.576000E+02	.562000E+02	.547000E+02	.533000E+02	.518000E+02
20	.502000E+02	.488000E+02	.472000E+02	.457000E+02	.441000E+02
	.423000E+02	.406000E+02	.388000E+02	.370000E+02	.352000E+02
	.333000E+02	.312000E+02	.291000E+02	.267000E+02	.243000E+02
	.216000E+02	.182000E+02	.142000E+02	.930000E+01	.450000E+01
	.000000E+00	.000000E+00	.000000E+00	.000000E+00	.000000E+00
	.000000E+00	.000000E+00	.000000E+00	.000000E+00	.000000E+00
25	.000000E+00	.000000E+00	.000000E+00	.000000E+00	.000000E+00

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1 Having now described the invention in detail as
required by the patent statute, those skilled in the art
will recognize modifications and substitutions to the
embodiment disclosed herein. Such modifications and
5 substitutions are within the scope and intent of the
invention as defined in the following claims.

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Claims

1. An energy management system, for vehicles employing a limited energy storage system, comprising:

means for receiving power status data from the energy storage system;

means for storing a plurality of predetermined driving profiles;

selection means for selection by the driver of one of said driving profiles;

calculation means connected to the receiving means and storage means for calculating range for the limited energy storage system based on the selected driving profile; and,

output means to display the range calculation to the driver.

2. An energy management system as defined in claim 1 wherein the driving profiles include predetermined data for standard driving cycles.

3. An energy management system, for vehicles employing a limited energy storage system, comprising:

means for receiving power status data from the energy storage system;

means for storing a plurality of predetermined driving profiles including data supplied by a vehicle navigator for route segments between a present position and a desired destination;

selection means for selection by the driver of one of said driving profiles;

calculation means connected to the receiving means and storage means for calculating range for the limited energy storage system based on the selected driving profile; and

output means to display the range calculation to the driver.

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4. An energy management system as defined in claim 1 further comprising means for storing energy storage system status data from the receiving means as a function of time and wherein the driving profiles include memorized energy storage system energy consumption data stored by the energy storage system status data storage means.

5. An energy management system as defined in claim 1 wherein the limited energy storage system comprises a battery, further comprising controllable means for charging the battery and wherein the calculation means includes means for determining a battery charging profile based on the energy storage system status data and means for controlling the battery charging means to match the charging profile.

6. An energy management system as defined in claim 1 wherein the output means comprises a menu-driven display and the selection means comprises interactive selection keys for the menu.

7. An energy management system as defined in claim 1 further comprising:

a plurality of vehicle subsystem sensors for determining subsystem status and a second plurality of environmental sensors for receiving data on perimeters effecting energy consumption by the vehicle said subsystem sensors and environmental sensors connected to the calculation means and wherein the calculation means includes means for comparing inputs from said subsystem sensors and said environmental sensors for detection of inefficient energy consumption through inconsistency between one of said subsystem sensors and one of said environmental sensors and means for displaying on the output means such detected inefficient energy consumption.

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8. An energy management system as defined in claim 7 further comprising control means for disabling vehicle subsystems and wherein the calculation means further comprises means for activating the control means responsive to detected energy inefficiency.

9. An energy management system as defined in claim 1 wherein the limited energy storage system comprises multiple storage elements with differing rates of charge and discharge, further comprising means for controllably directing regenerated energy from braking of the vehicle to a selected one of the storage elements and wherein the calculation means includes means for controlling the directing means.

10. An energy management system for vehicles having limited energy storage comprising:

a plurality of vehicle subsystem sensors for determining subsystem status and a second plurality of environmental sensors receiving data on parameters affecting energy consumption by the vehicle;

a calculation means for comparing inputs from said subsystem sensors and said environmental sensors for detection of inefficient energy consumption through inconsistency between one of said subsystem sensors and one of said environmental sensors; and

means for a signal output responsive to detection of inefficient energy consumption.

11. An energy management system as defined in claim 10 wherein the signal output means is interactive with a driver of the vehicle and comprises a display means connected to the calculation means for display of information concerning said inefficient energy consumption and recommendations to rectify the inefficient energy consumption.

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12. An energy management system as defined in claim 10 wherein the reacting means signal output means comprises means for directly controlling vehicle subsystems, said controlling means responsive to said calculation means.



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**ENERGY MANAGEMENT SYSTEM FOR VEHICLES HAVING LIMITED
ENERGY STORAGE**

Abstract

The Energy Management System comprises an electronic module 10 which incorporates a microcontroller 12 as a calculation engine and means for controlling various systems of an electric vehicle or other vehicle having limited energy storage. A variety of sensors including battery sensors 18, temperature sensor 20, current sensor 22, temperature sensors 24, 26, 28, 30, speed sensor 32, accelerometer 34, and ignition switch 36 provide information for the Energy Management System to derive control parameters for the systems. Automatic control of heating and air conditioning system 56, external lighting system 58 and the operation of motor controller 54 as well as display of information, status and queries to the driver are controlled by the Energy Management System and range and navigation recommendations are made based on predefined driving profiles maintained in the system.

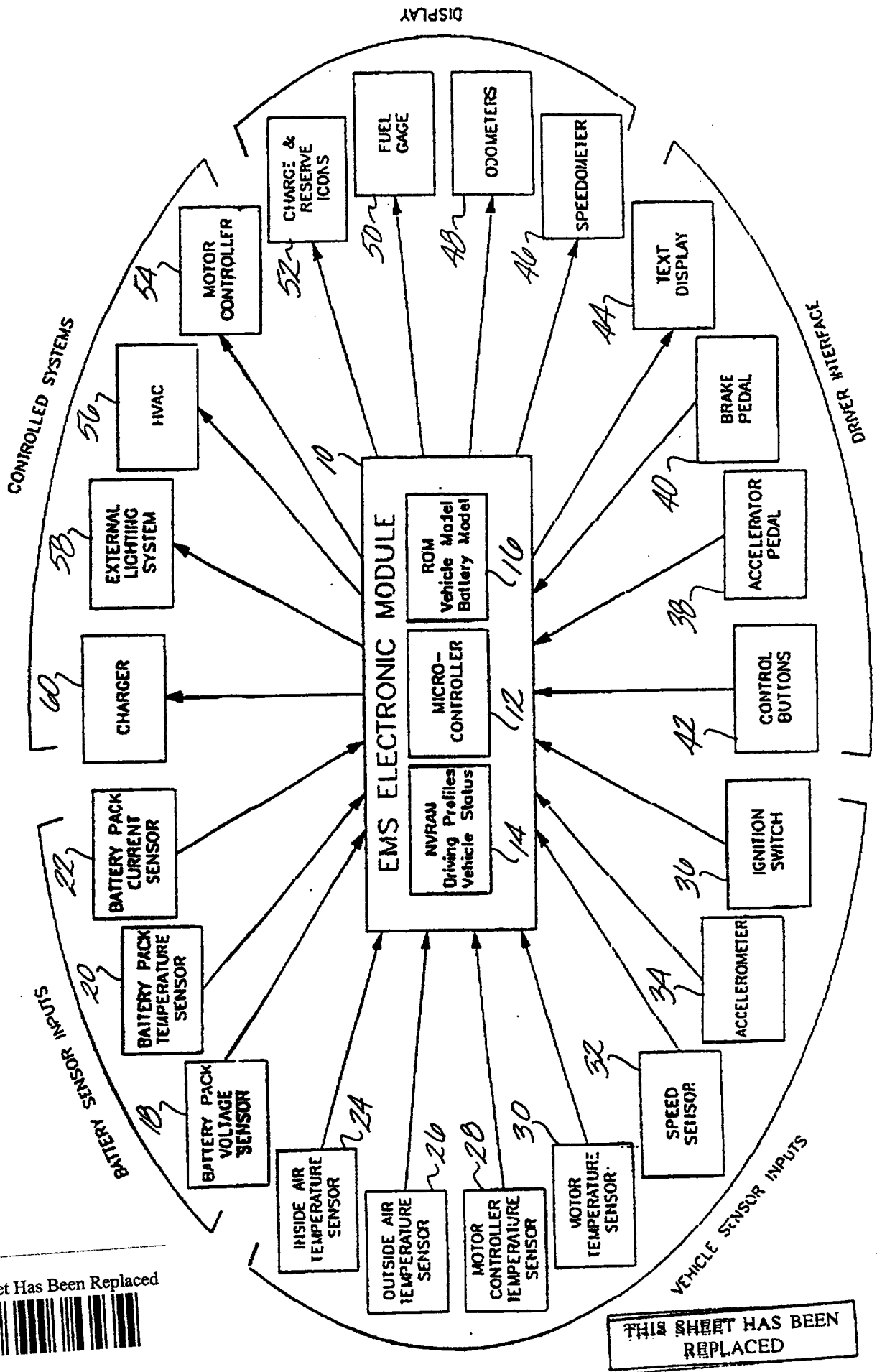
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FIG. 1

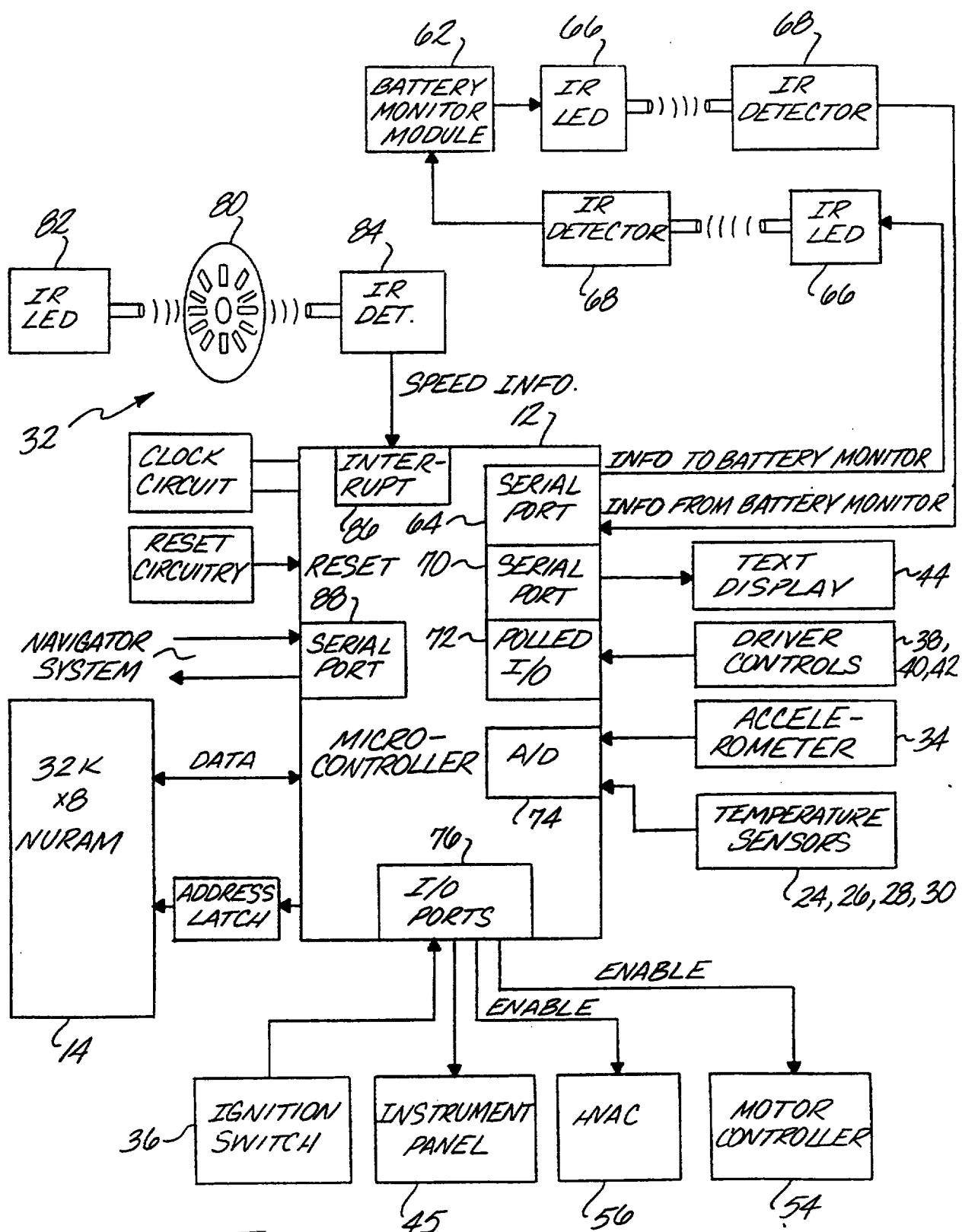


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FIG. 2



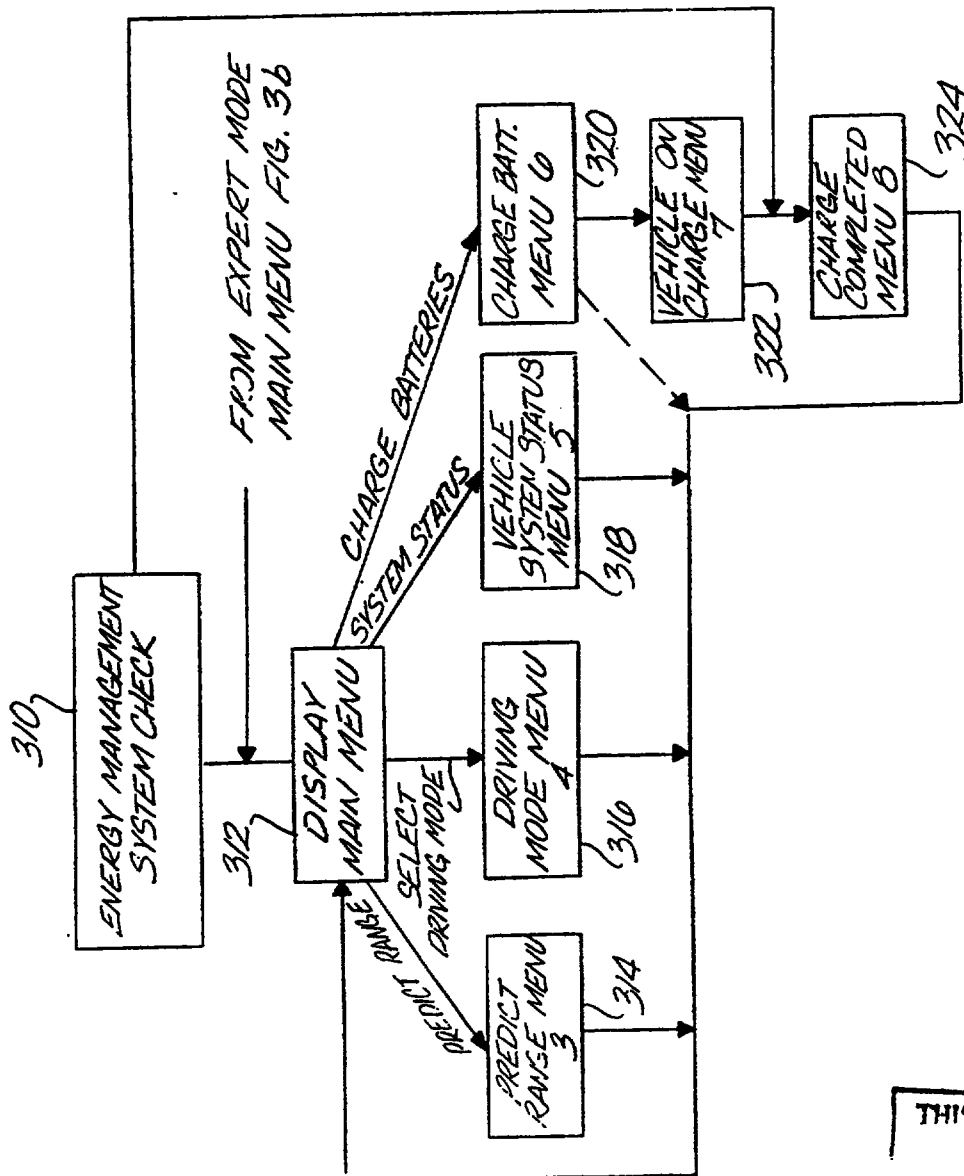
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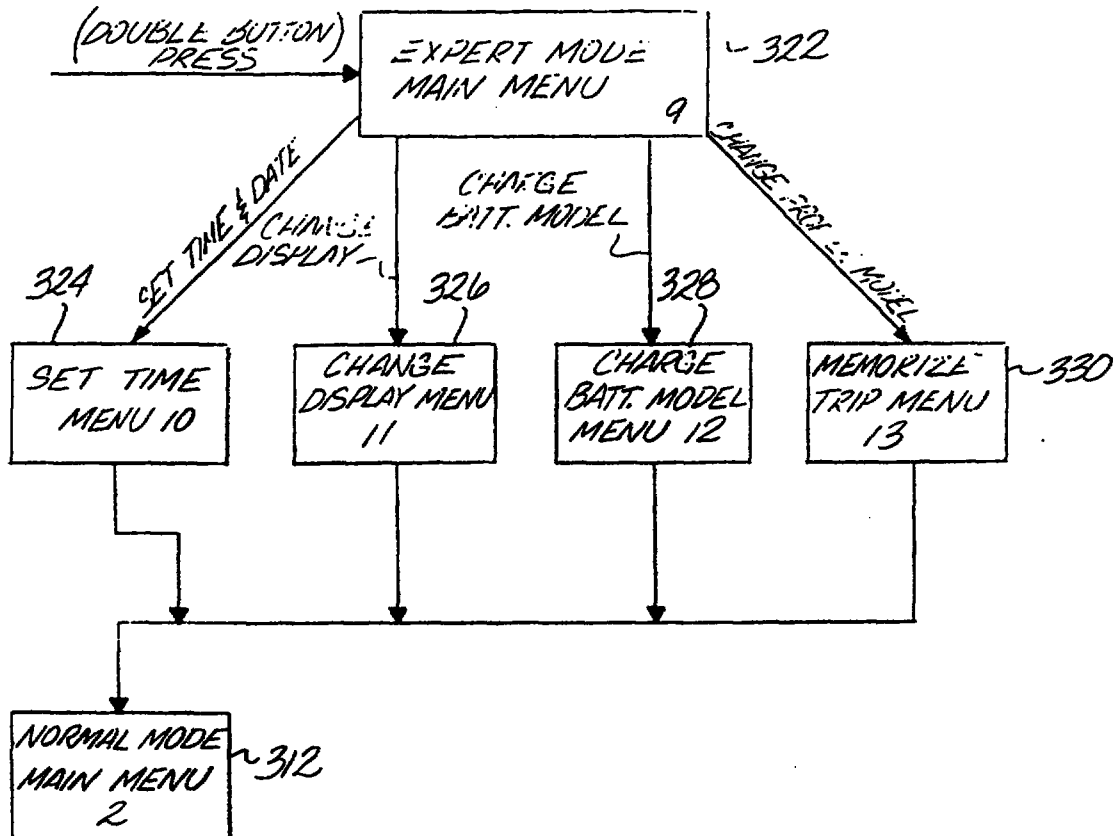
FIG. 3a



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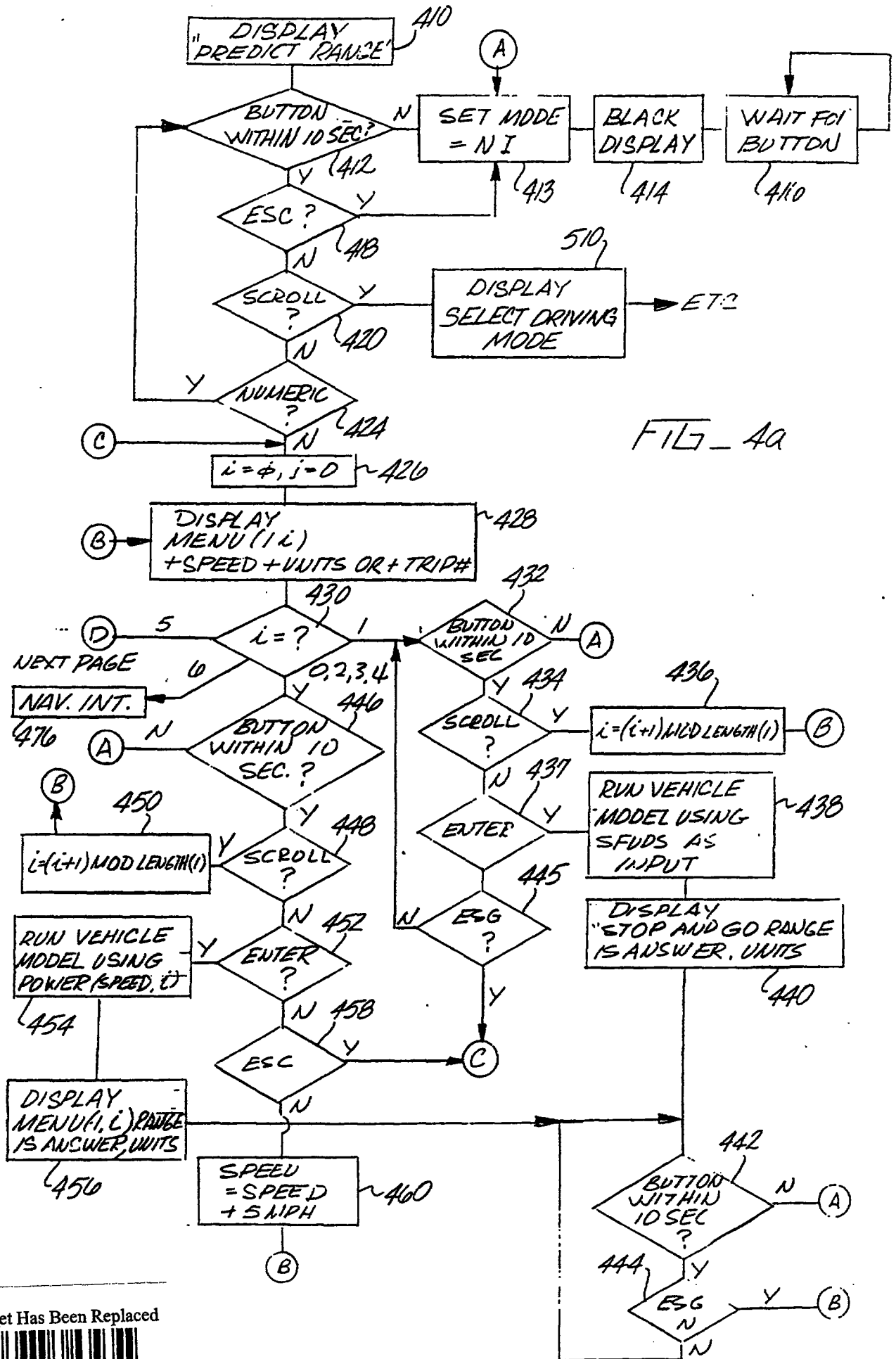
FIG. 36



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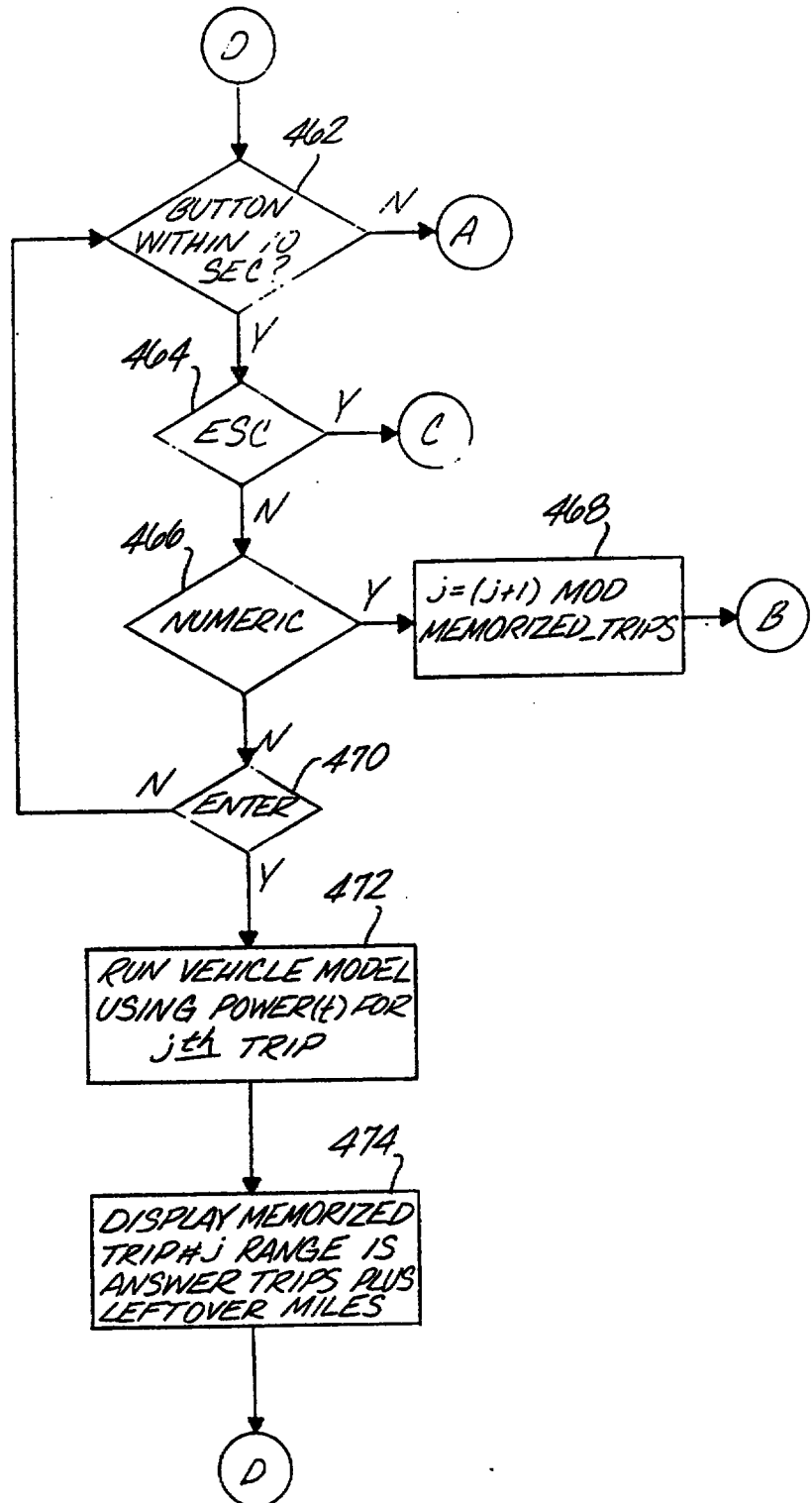


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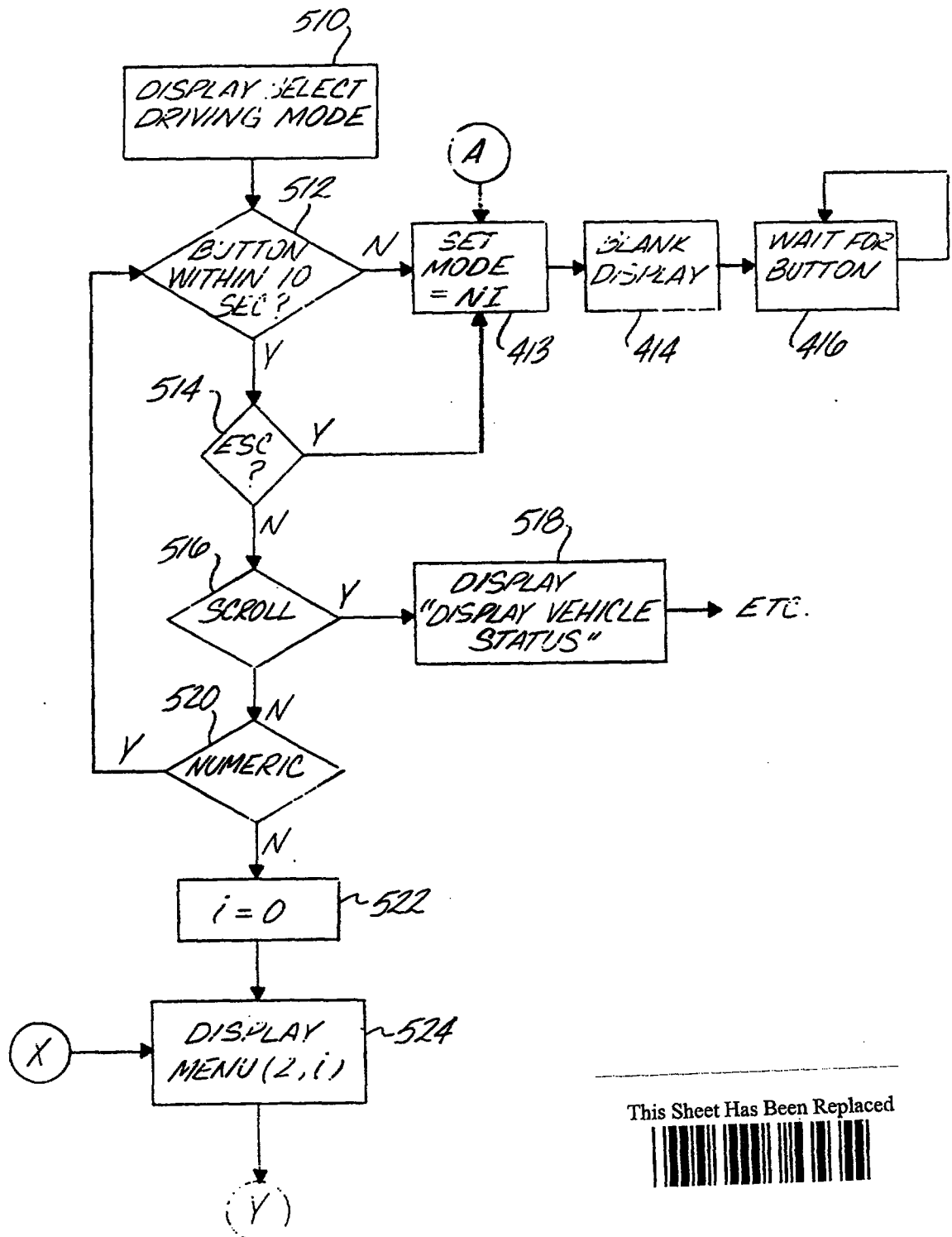
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FIG. 46



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FIG. 5a

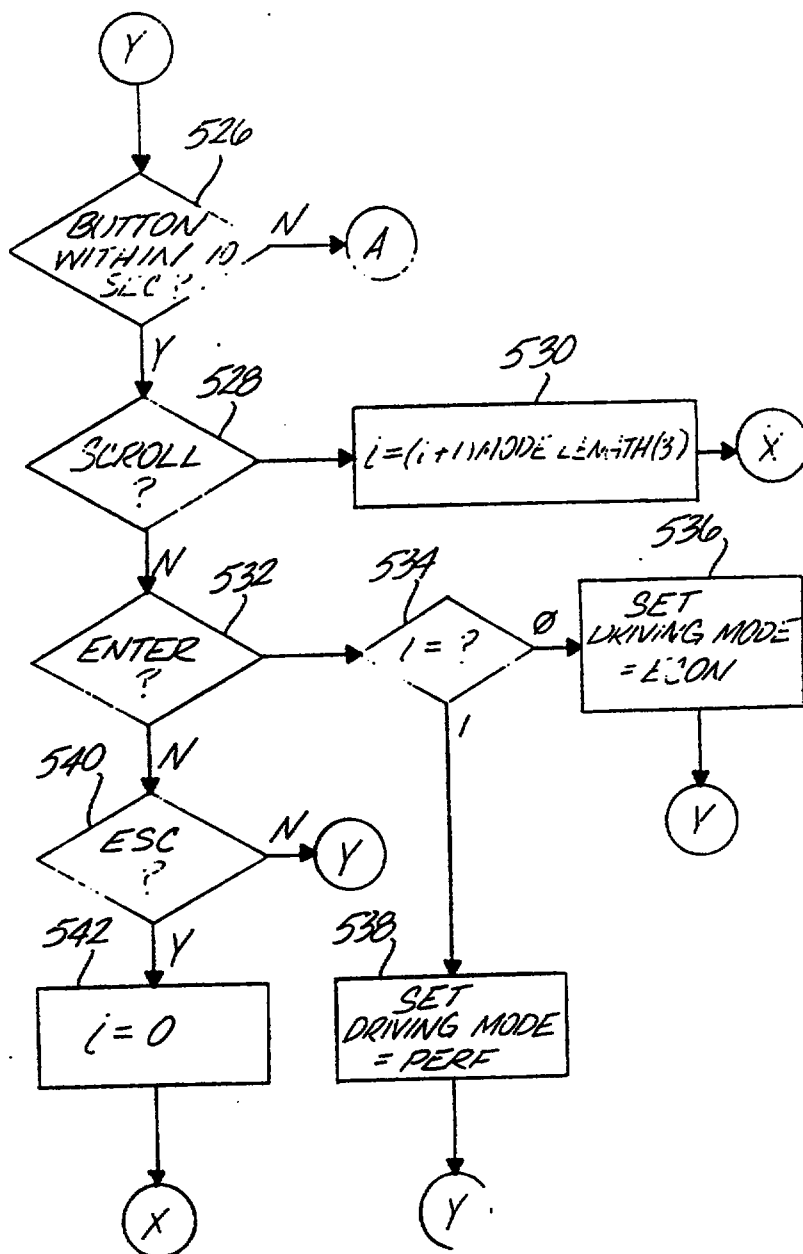


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FIG. 5b

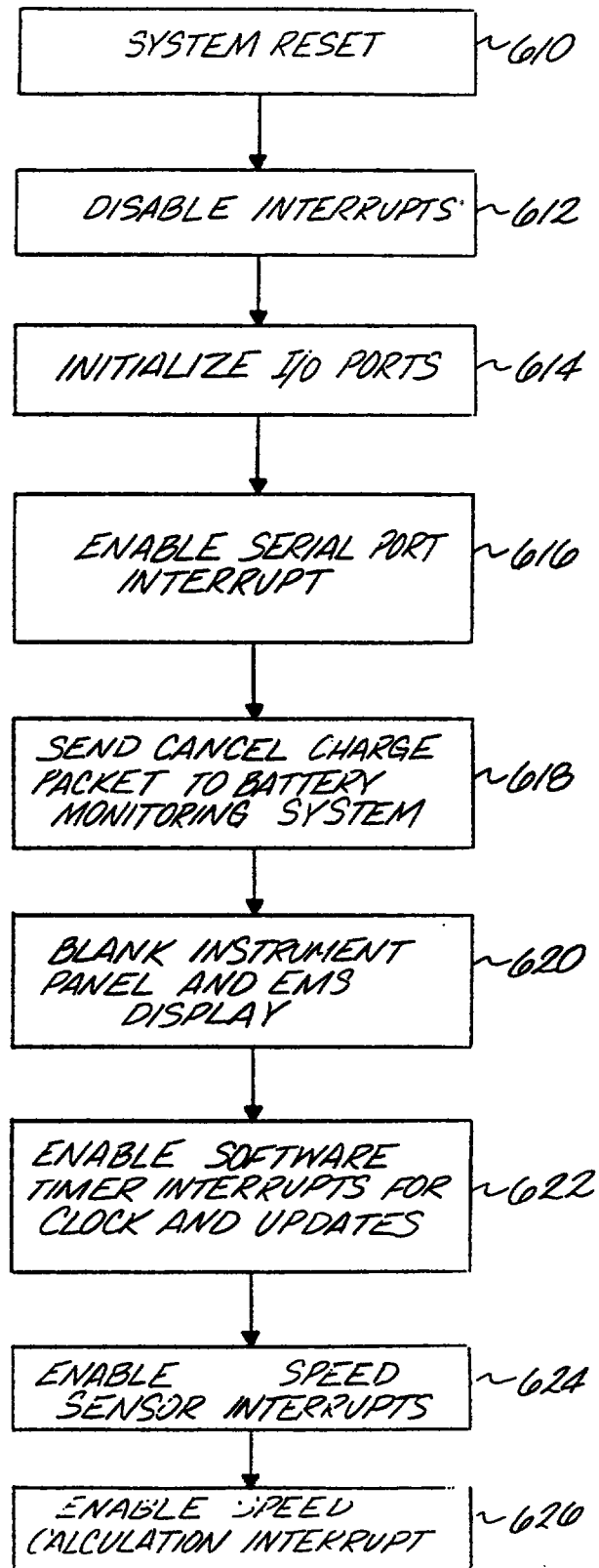


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FIG. 6a



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TO FIG. 6b

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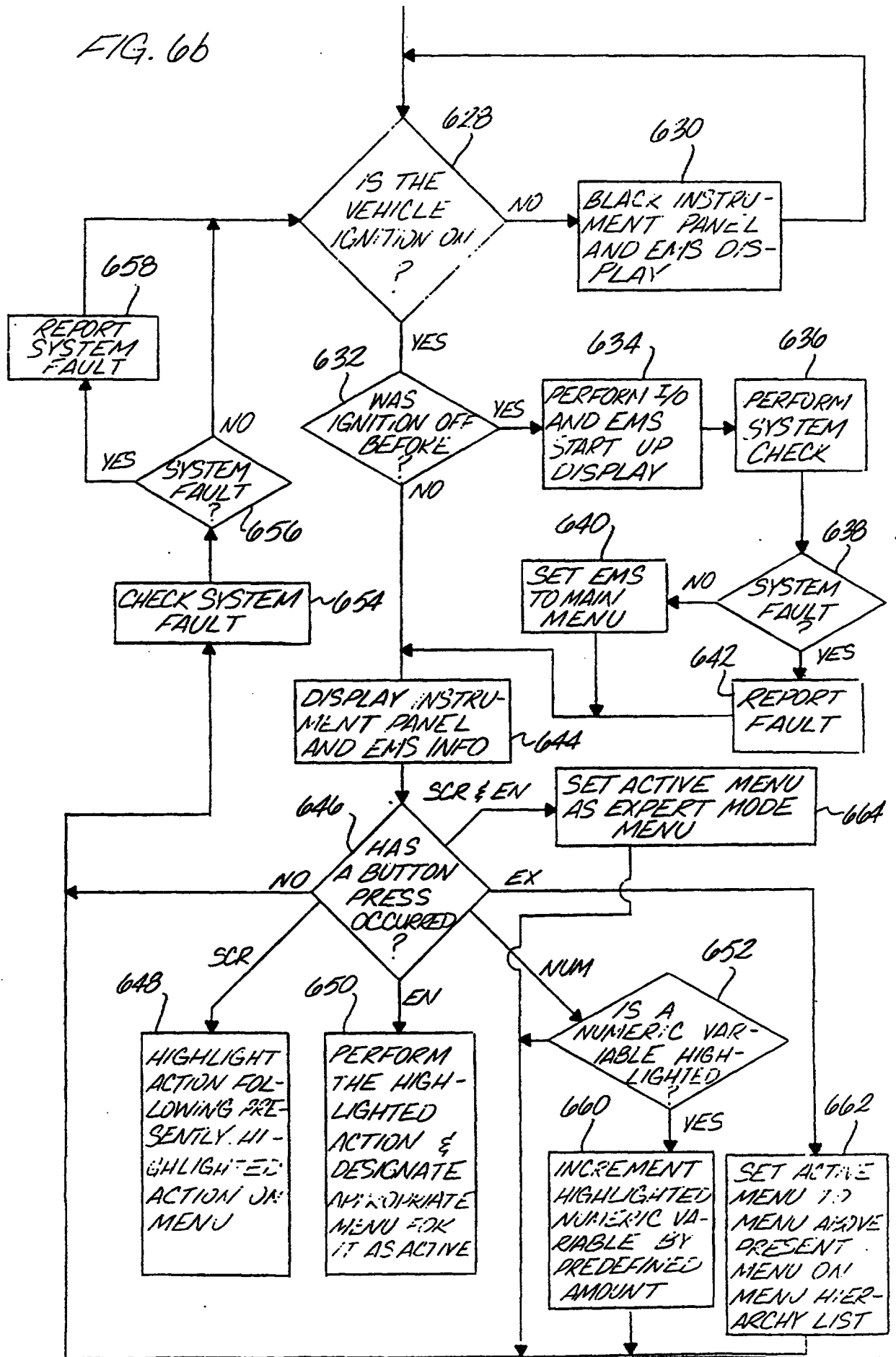
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FROM FIG. 60

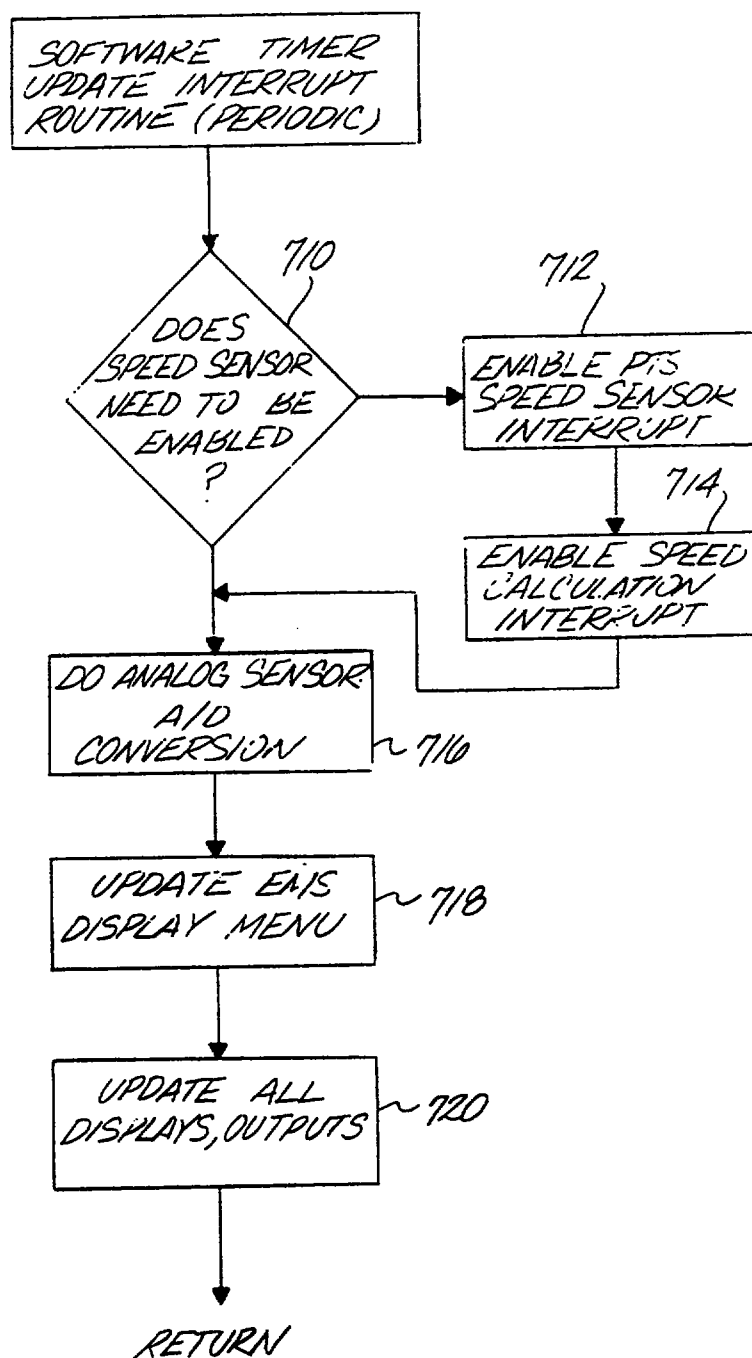
FIG. 66



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FIG. 7a

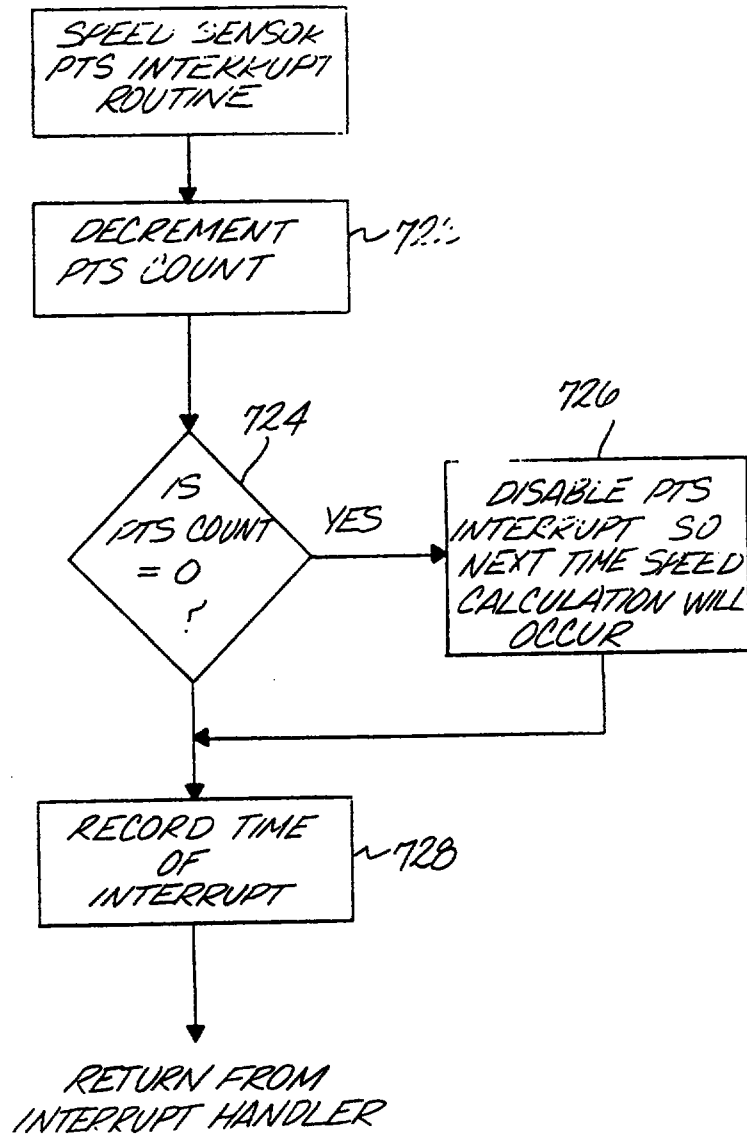


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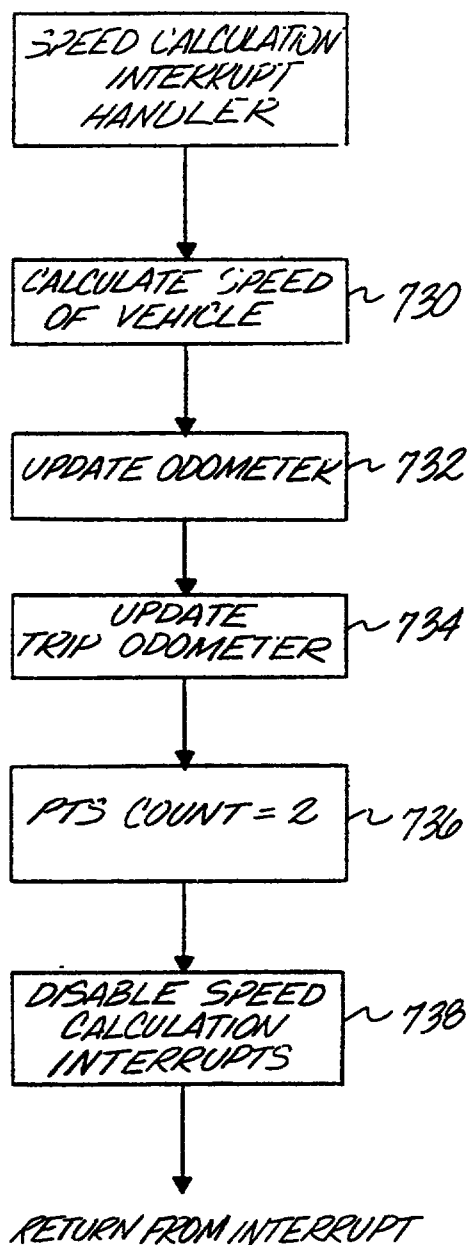
FIG. 7c



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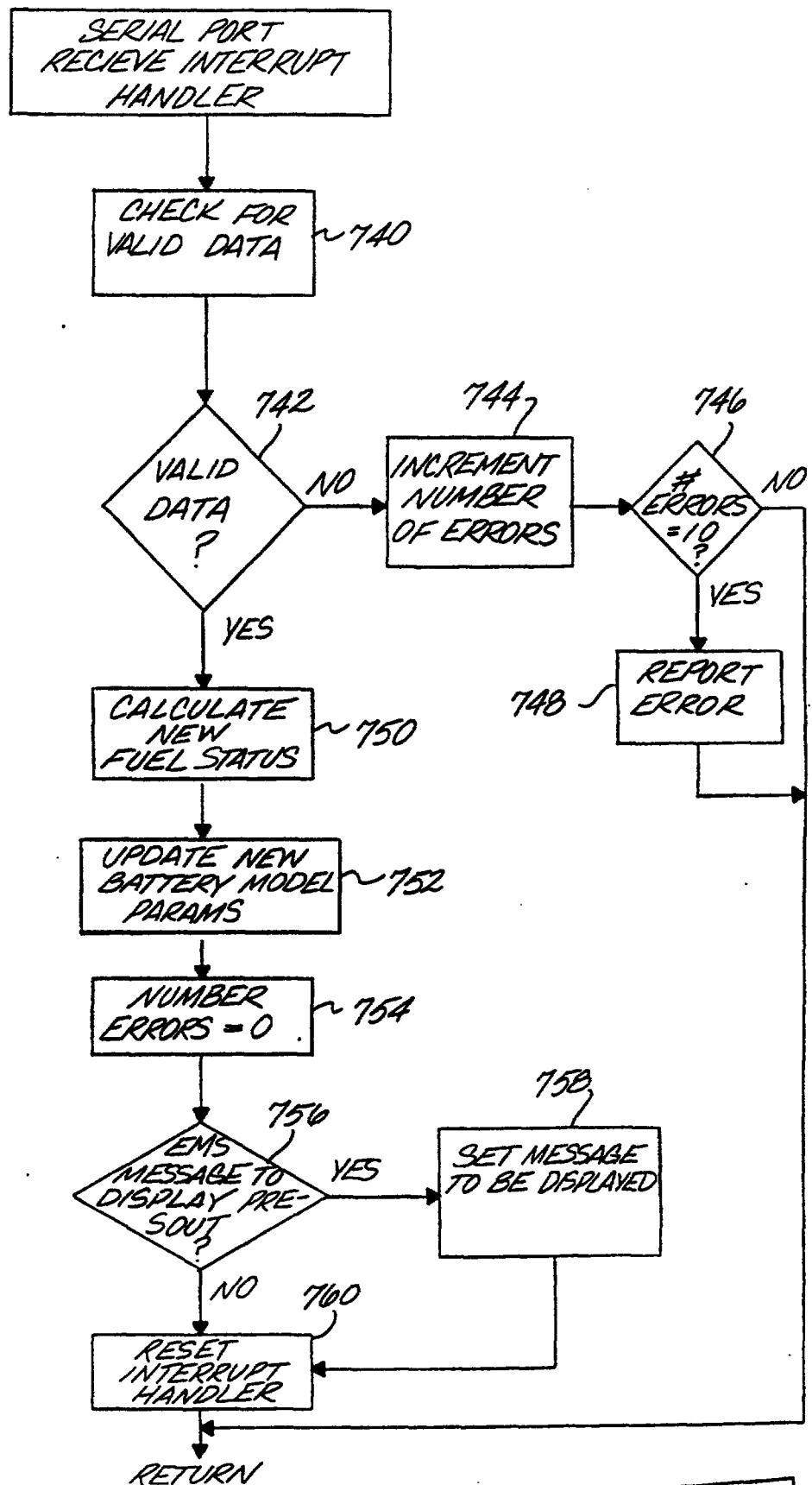
FIG. 7C



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FIG. 7d

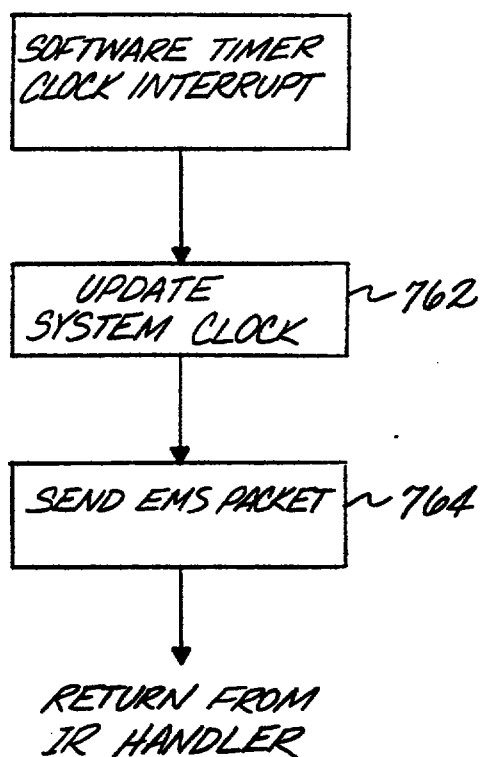


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FIG. 7e

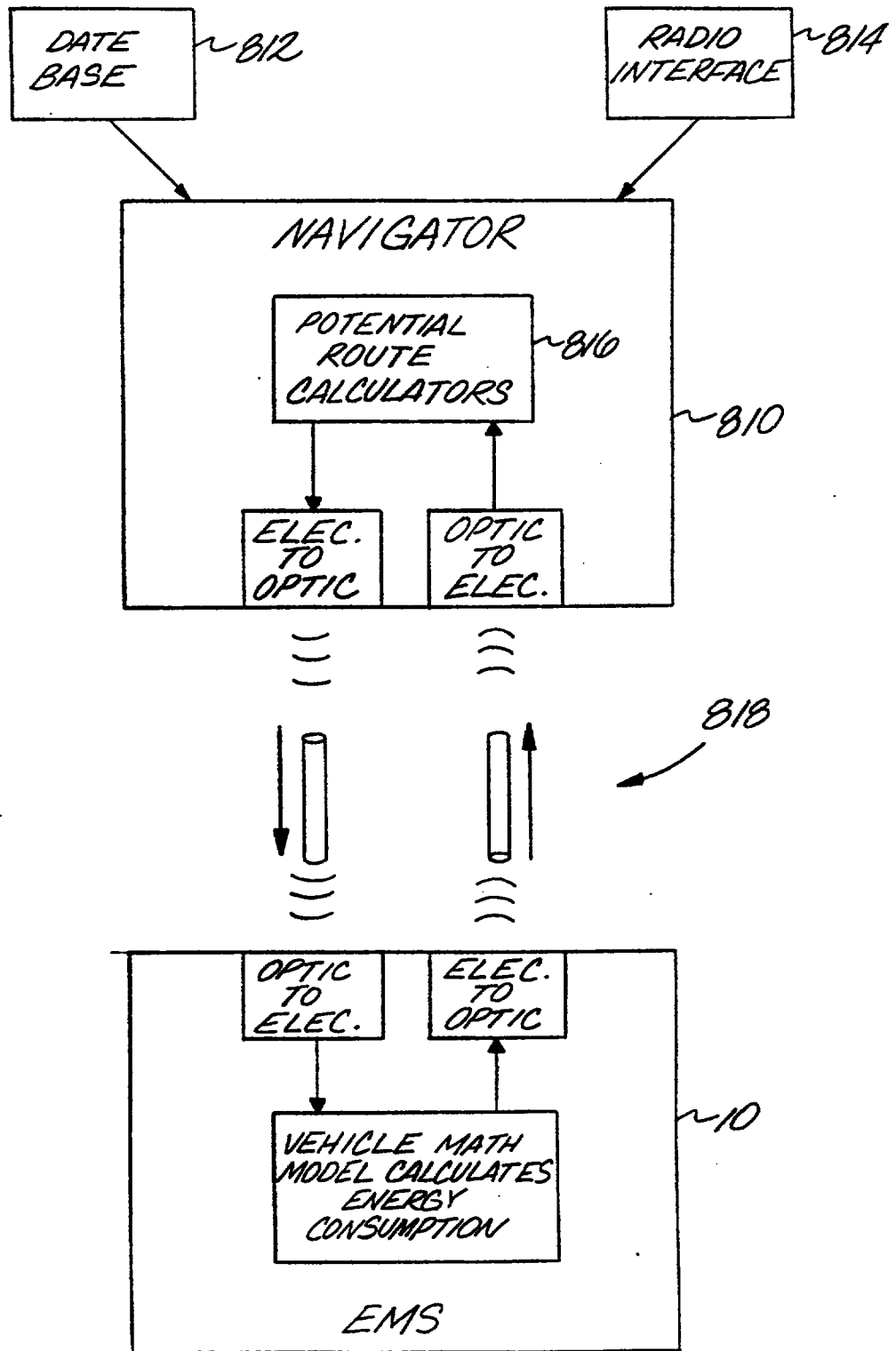


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FIG. 8

TRAFFIC INFO
FROM CALTRANS



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FIG. 9a

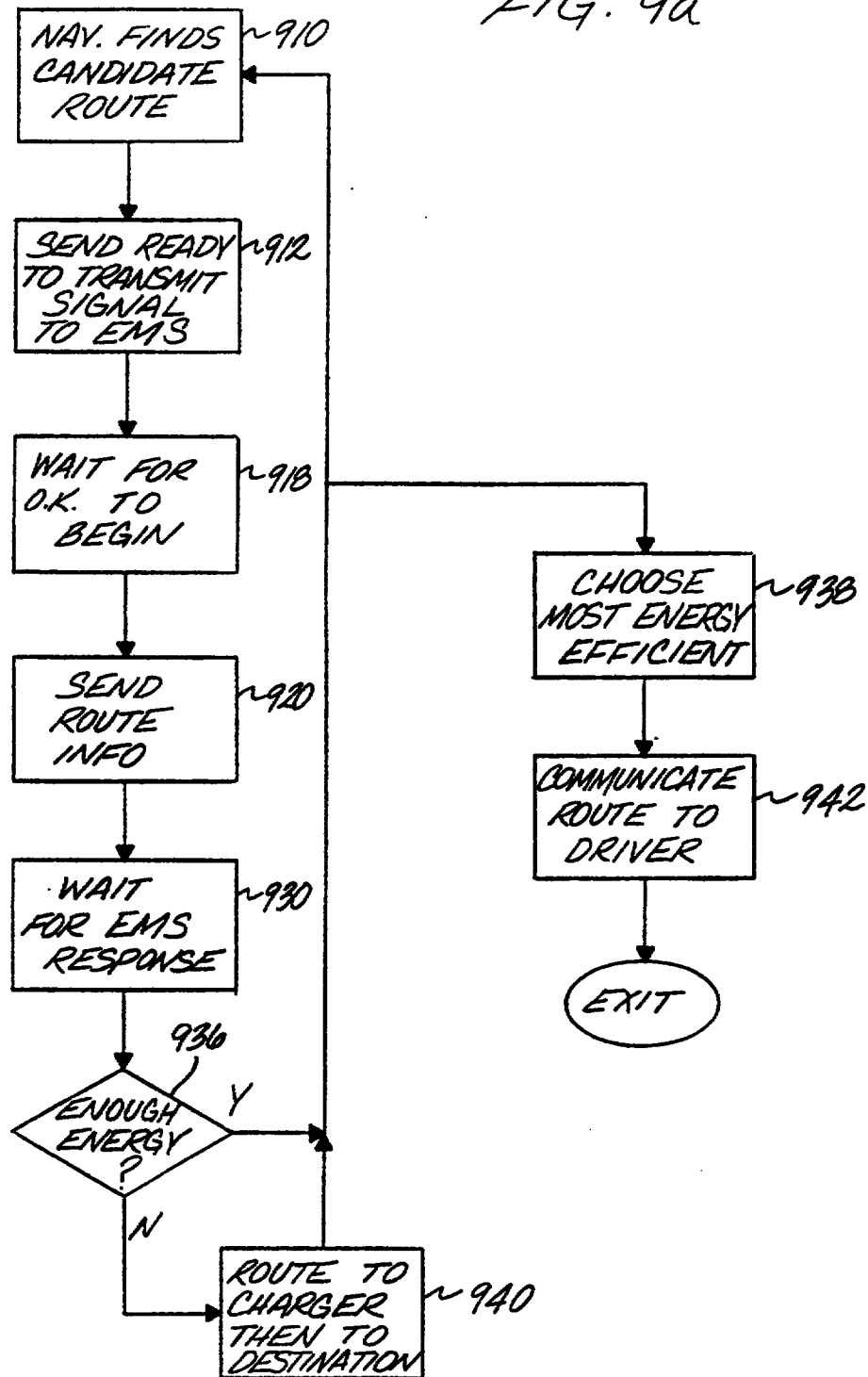
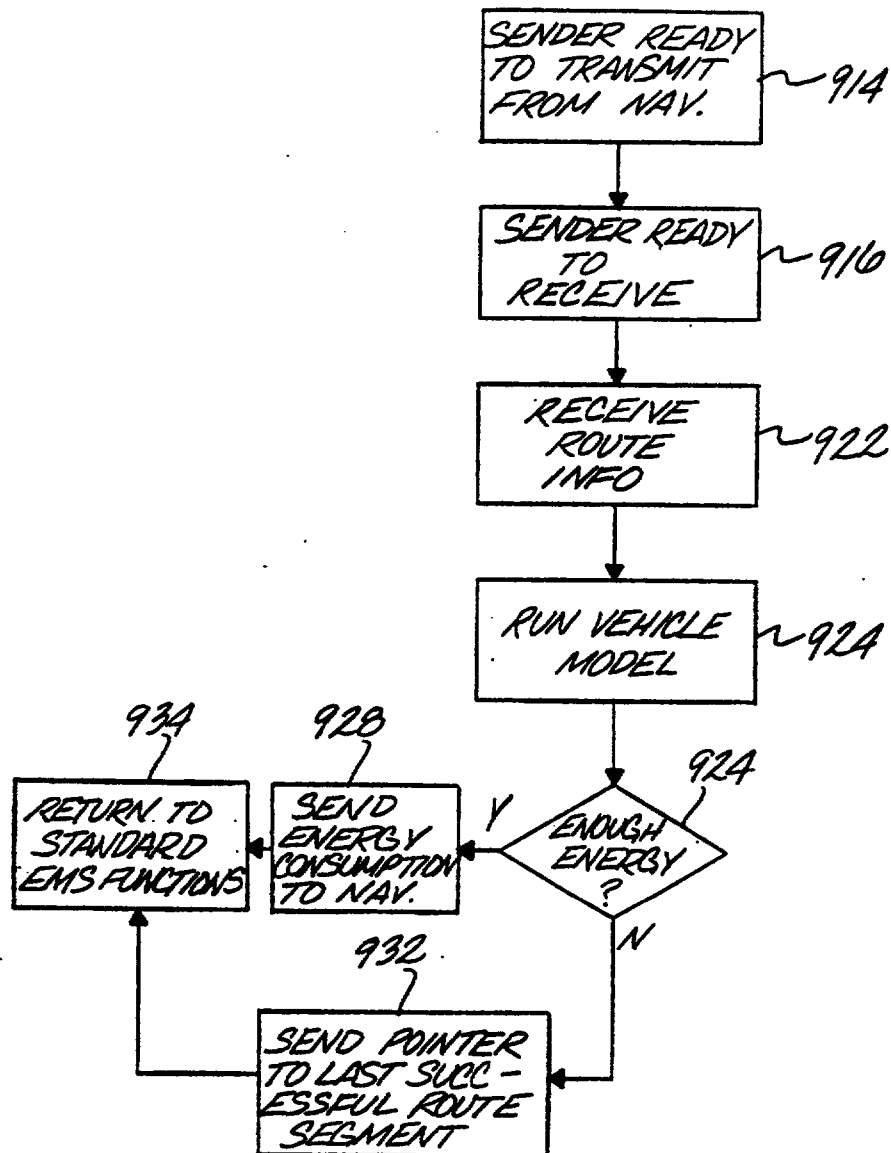


FIG. 96



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Field of the Invention

25 Background of the Invention

Environmental pollution is requiring the development and implementation of alternatively powered vehicles to supplement or replace present conventional internal combustion powered passenger vehicles. Recent developments in the technology of electric and other alternative energy vehicles allows performance of those vehicles to approach that of internal combustion engine powered vehicles in all areas with the exception of driving range. Using electric vehicles as an example, present battery technology limits the amount of onboard energy storage available for electric vehicles and the likelihood that limited locations having recharging

1 facilities will be available in the near term requires
systems integrated in the vehicle to inform the driver of
battery status and driving range available or,
alternatively, destinations within range of the vehicle.

5 Various battery management systems have been proposed
in the prior art to estimate the state of charge of the
vehicle battery and remaining vehicle range. Examples of
these systems are described in the paper by C.C. Chan and
K.C. Chu, "Intelligent Battery Management System,"
10 presented at the Electric Vehicle Symposium 9, November
13-16, 1988 in Toronto, Ontario, Canada and the SAE
technical paper by A.F. Burke, "Evaluation of State of
Charge Indicator Approaches for E.V.'s," presented at the
International Congress and Exposition of the SAE, Detroit,
15 Michigan, February 27-March 3, 1989. These systems are
typically very limited in the information provided to the
electric vehicle user.

For some time navigation systems have been under
development for use with ground vehicles. Exemplary of
20 the prior art in this field are U.S. Patent Nos. 4,926,336
to Yamada, 4,984,168 to Meukirchner, 4,992,997 to Nimura
et al. and 5,121,326 to Moroto et al. Information
provided by such prior art navigation systems can be of
particular use to electric vehicle operators, however,
25 supplementing of data and calculation routines of the
prior art navigators to incorporate information critical
for electric vehicle operation would allow use of a
navigation system to supply information to the electric
vehicle operator for energy efficient route planning and
30 alternative route planning where insufficient range is
available from the battery pack in the vehicle.

The present invention combines and improves the prior
art systems to provide an energy management system for
optimum use of an electric vehicle by allowing the driver
35 to select performance modes, driving profiles and
destinations while informing the driver of vehicle status,

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1 range, navigational route capability and vehicle
efficiency control.

Summary of the Invention

5 The present invention is applicable to vehicles
employing limited energy storage systems including, but not
limited to, battery systems, inertial energy systems and
hybrid electric systems. The embodiment disclosed herein
employs a battery storage system. The electric vehicle
10 energy management system incorporates an electronics
module having a microcontroller for sensing, control and
calculation, and memory for maintaining driving profiles,
vehicle status information and mathematical models for the
vehicle and battery systems. A battery sensor package
15 provides status information to the electronic module for
the battery voltage, temperature and current for use with
the battery model. Vehicle sensor inputs to the
electronic module include temperature inside the vehicle,
outside air temperature, temperature of the motor
20 controller, temperature of the motor, speed of the vehicle
and acceleration of the vehicle for use with the vehicle
model. A driver interface, which incorporates an
accelerator pedal and a brake pedal for motion control of
the vehicle and a plurality of control buttons for control
25 of the electronic module and a text display for output
from the module to the driver. Normal display functions
for safe operation of the vehicle, such as speedometer,
odometers and battery status are provided from the
electronic module, using standard analog or digital
30 displays in an instrument cluster on the vehicle
dashboard.

The microcontroller employs the data received from
the battery sensor inputs for range calculations based on
the battery model stored in the memory. The battery model
35 includes experimentally determined formulas or tables
describing the voltage and current relationship over the
range of allowable depths of discharge and the model of

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1 cycle life based on battery charge and discharge history.
The vehicle model incorporates the information from the
battery model and the efficiencies of the electric motor,
transmission and motor controller as functions of speed,
5 load and temperature as well as losses due to rolling
friction, aerodynamics and hill climbing. The
microcontroller employs the vehicle model for range and
efficiency calculations based on the vehicle sensor
inputs. The driving profiles stored in the memory are
10 employed by the microcontroller for calculation of power
consumption based on "standardized" driving profiles, such
as stop and go, freeway cruising, and hill climbing, or
profiles obtained by memorizing the power consumption
history of trips unique to the driver of the vehicle. The
15 microcontroller provides calculation for the energy
management system to predict range of the electric vehicle
based on the driving profile and speed selected by the
driver through the driver interface.

In addition to the stored profiles, the energy
20 management system interfaces with a vehicle navigator
employing a database of street routes and other static and
dynamic navigation information for calculation of energy
efficient routes to a destination based on the vehicle
model and alternative routes to battery charging stations
25 if the battery condition does not allow sufficient range
to reach the desired destination.

The energy management system through its
microcontroller provides active control of vehicle systems
including the charging system for the battery pack,
30 internal and external lighting systems, heating,
ventilating and air conditioning systems for the vehicle
and the drive motor controller.

1 Brief Description of the Drawings

 The present invention is best understood with reference to the following drawings and accompanying detailed description wherein✓

5 FIG. 1 is a block diagram of the generalized energy management system and the systems and sensors interfaced to the EMS.

 FIG. 2 is a schematic of an embodiment of the energy management system employing a standard microcontroller.

10 FIGS. 3a and 3b are a block diagram of the menu hierarchy for the text display of the driver interface from the energy management system.

 FIGS. 4a and 4b are a flow diagram for range prediction by the energy management system.

15 FIGS. 5a and 5b are a flow diagram for selection of the driving mode.

 FIGS. 6a and 6b are a flow diagram of the general control program for the energy management system microcontroller.

20 FIGS. 7a and 7b are flow diagrams of the interrupt driven data input and output from the vehicle sensors, battery system sensors and displays.

 FIG. 8 is a block diagram of the energy management system interface with the vehicle navigation system.

25 FIG. 9a is a flow diagram of the energy management system interface with the navigator.

 FIG. 9b is a flow diagram of the navigator interface with the energy management system.

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1 Detailed Description of the Invention

Referring to the drawings, FIG. 1 shows the relationship of the energy management system (EMS) to the various sensor inputs, controlled system outputs, driver interface and display for the vehicle. The energy management system electronic module 10 incorporates a micro-controller 12 as a calculation engine and means for controlling the various systems of the electric vehicle. In the embodiment shown in the drawings, an Intel Model 10 196KR processor is employed. The Memory systems, including a nonvolatile random access memory (NVRAM) 14 and a read only memory (ROM) 16 provide data storage for the microcontroller. As will be discussed in greater detail subsequently, data for driving profiles, vehicle status and operational models including a battery model and vehicle model are stored in the memory. Those skilled in the art will recognize that various memory configurations and combinations may be employed.

The EMS receives inputs from a variety of sensors. Battery sensors including a battery pack voltage sensor 20 18, a battery pack temperature sensor 20 and a battery pack current sensor 22, provide information on the battery for use by the EMS. Various vehicle sensor inputs including an inside air temperature sensor 24, an outside 25 air temperature sensor 26, a motor controller temperature sensor 28, a motor temperature sensor 30, a speed sensor 32 and accelerometer 34 and an ignition switch 36 provide data input to the EMS for the various vehicle systems. The designation "ignition switch" is used for easy 30 understanding by drivers of internal combustion engine vehicles and comprises an on-off switch enabling the operation of the electric vehicle.

The driver interface to the EMS comprises a standard accelerator pedal 38 and brake pedal 40 for direct control 35 of the vehicle. In the present embodiment, a series of four control buttons 42 are employed for control of the EMS system in response to menus displayed for the driver

1 on a text display 44. The various control buttons and
their function and the menus associated with the EMS will
be described in greater detail subsequently.

5 Other displays to the driver of the electric vehicle
are controlled by the EMS including a standard speedometer
46, trip and continuous odometers 48, a fuel gauge 50 and
charge and reserve icons 52. The fuel gauge provides a
visual indication of charge remaining in the battery and
is again analogized for familiarity to a "fuel" gauge in
10 an internal combustion vehicle. The charge and reserve
icons inform the driver of connection of the electric
vehicle to a charger for recharging of the batteries and
operation of the battery in a reserve mode for very
limited distance travel with the battery in an essentially
15 depleted state.

The microcontroller of the EMS is interfaced with
various vehicle systems to control their operation. These
systems include the motor controller 54 which activates
the traction motor driving the electric vehicle. The
20 heating, ventilation and air-conditioning (HVAC) system 56
and external lighting system 58 of the vehicle are
controlled by the EMS based on inputs from the driver
interface and energy efficiency considerations as will be
described in greater detail subsequently. The charger 60
25 for the battery in the vehicle is controlled by the EMS to
recharge the battery when connected to a charging station.

As best seen in FIG. 2 for the present embodiment of
the system, the battery sensor inputs and charger system
are incorporated in a self-contained battery monitoring
30 module 62 which communicates with the microcontroller
through a serial port 64. Those skilled in the art will
recognize that the battery monitor circuit module could be
an integral part of the EMS itself. An electro-optical
interface employing IR LEDs 66 and IR detectors 68 is
35 employed for the battery system. Selection of the
charging algorithm to be used in charging the batteries in
the electric vehicle is accomplished by the EMS based on

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1 input from the driver on available charging time. The
microcontroller employs a selection of charging algorithms
which takes into account the battery pack history and
current state of charge to assist in extending the cycle
5 life of the battery. Battery pack replacement cost is
substantial, consequently, this aspect of the EMS provides
high-cost efficiency for the electric vehicle. The
charging algorithm is altered by the EMS based on input
from the driver identifying the amount of time the vehicle
10 will be connected to the charging site. If the vehicle is
to be unused for an extended period of time, as an
example, the EMS employs a charging algorithm to equalize
the battery pack, normally a time consuming charging cycle
important to extending battery pack life. If the charging
15 period is shorter, the charging algorithm employed by the
EMS is tailored to accomplish maximum charge within the
allotted time without degradation of the battery pack
life. Battery charging algorithms employed in the present
embodiment are exemplified in the publication by Linden,
20 David, Handbook of Batteries and Fuel Cells, McGraw-Hill,
1984, pp. 14-79 through 14-92.

State of the art motor controllers provide for
returning regenerated power to the energy storage system
of the vehicle during electrodynamic braking. In vehicles
25 with energy storage systems comprised of two or more types
of storage devices having differing rates of charge and
discharge, the EMS, through the I/O port, directs the
motor controller to select the particular energy storage
subsystem which is to receive the regenerated energy.

30 Communications with the driver are accomplished by
the microcontroller through a serial port 70 to the text
display 44 and from the driver controls through a polled
I/O port 72. The accelerator pedal 38 and brake pedal 40
as portions of the driver controls are routed through the
35 EMS which converts the inputs made by the driver to output
signals enabling the motor controller through a standard
I/O port. Control of the motor controller and brakes is

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1 accomplished in a standard manner and will not be detailed
in this disclosure. The other driver controls comprise
the four control buttons 42 previously referenced. In the
embodiment shown in the drawings, these buttons comprise
5 a SCROLL key, an ENTER key, a NUMERIC key and an ESCAPE or
EXIT key. These key designations are used for easy
understanding by those familiar with common computer entry
and may employ different names in a preferred embodiment.

Output to the text display is accomplished in a menu
10 format. The menu hierarchy employed in the present
embodiment is shown in FIG. 3a and 3b. Initialization of
the system places the EMS microcontroller in the energy
management system check identified in block 310. The
initial display of the system is the main menu identified
15 in block 312. In the present embodiment, the text display
is a four line by twenty character system. Normally the
EMS system operates in a "non-expert" (NI) mode. This
mode provides simple functional response to the control
buttons operated in response to the various menus. The NI
20 mode is initiated by the driver depressing a single
control button. The functions available to the driver in
the NI mode are predict range, memorize trip, select
driving mode, display vehicle status and charge battery.
These functions are provided in separate menus identified
25 in blocks 314, 316, 318 and 320; respectively.

If the driver depresses two control buttons
simultaneously, the EMS initiates an "expert" (E) mode
which provides additional, more complex functions for
control of the system. The EXPERT MODE menu represented
30 in block 322 allows the driver to reconfigure the EMS
system by setting the time and date represented as a menu
in block 324 and change the display identified as menu
block 326 which allows a change of the language employed
by the display and the units employed (English or metric)
35 by the EMS system and displays. A CHANGE BATTERY MODEL
menu represented in block 328 allows the driver to change
the battery model or change the charging algorithm for the

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1 battery as previously described. The final menu available
in the expert mode is the MEMORIZE TRIP menu identified in
block 330 which allows the EMS to memorize the energy
consumption of a frequently employed driving path for the
5 vehicle.

The various menus of the system are selected by
pushing the SCROLL button until the function of choice
appears followed by pushing the ENTER button. Once a menu
is selected, the various functions of the menu are
10 selected employing the SCROLL button followed by pressing
the ENTER button at the desired function to confirm the
selection. For various functions, an option is provided
to the driver in the form of a numeric value which may be
increased through set steps in a wrap-around fashion by
15 pressing the NUMERIC button. The ESCAPE key is provided
for the driver to reverse menu selection to return to the
next higher menu level. The functions of the EMS as
selected from the menus will now be described.

The PREDICT RANGE menu when selected provides a
20 series of choices: "level ground at xx mph," "stop and
go," "constant speed uphill at xx mph," "constant speed
downhill at xx mph," "constant speed up and down at xx
mph" and any one of up to nine memorized trips. The
program format of this menu is shown in Table 1. The
25 driver uses the scroll button to select the type of
driving profile which he desires. Once the proper profile
is displayed, he pushes the enter button to confirm the
selection. As an example, if the driver chooses "stop and
go" the EMS employs the vehicle model from the ROM with
30 the driving profile for "stop and go" conditions from the
NVRAM. The stop and go conditions data employed in the
present system is represented by the Simplified Federal
Urban Driving Cycle (SFUDS), a copy of which is provided
in Table 2. The format of the data required by the EMS to
35 calculate range from either power as a function of time or
velocity as a function of time follow that of the SFUDS
cycle shown in the listing provided in Table 2. This

1 driving cycle is represented by a series of vehicle
velocities at one second intervals over a driving time of
six minutes. From this information, the vehicle model
calculates the power required at each step and subtracts
5 the energy used at each step from that available in the
battery pack as calculated using the battery model from
the ROM assuming an initial state defined to the
micro-controller of the EMS through the serial port from
the battery monitor module. The EMS continues to run the
10 stop and go steps repeating the six minute cycle
consecutively until the calculated energy remaining in the
battery pack would no longer be able to provide the power
for the next step. The distance covered at each step is
accumulated and the reported range is that covered at the
15 last successful step. This information is reported to the
driver on the display as "range under stop and go
conditions is xxx miles."

If the driver selects from the PREDICT RANGE menu,
any of the other choices, with the exception of the
20 memorized trip, the speed parameter must be entered by the
driver to allow the EMS to make a range prediction. For
example, if the driver has selected on the menu "constant
speed downhill at xx mph," the numeric key is pressed by
the driver to change the desired speed. In the present
25 embodiment as identified in the programming application of
Table 1, a minimum speed of 20mph and a maximum speed of
80 mph is employed. The initial speed displayed in the
menu may start with a default value e.g., 30 mph, or the
last speed value employed by a selection on the EMS.
30 Pressing the numeric button would increment the speed by,
for example, five miles per hour for each button push to
the maximum programmable speed at which time the input
wraps to the lowest speed e.g., 20mph. When the driver
obtains the speed desired on display, the enter button is
35 pressed and the EMS then employs the vehicle model to
predict the range. In this case, the power calculation is
based on a constant condition which is derived from a

1 matrix of power required for the given profile and speed
selected.

The battery model and vehicle model employed in the
present system are based on the electric vehicle battery
5 performance application program DIANE disclosed in the
paper entitled: Users Guide to DIANE Version 2.1: A
Micro Computer Software Package for Modeling Battery
Performance in Electric Vehicle Applications, by W. W.
Marr, W. J. Walsh and P. C. Symons, June 1990, published
10 by the Energy Systems Division of the Argon National
Laboratory. The vehicle model provided in Appendix A of
the paper as modified for the present system is disclosed
in Appendix A to this application. Data employed in the
battery model by the present embodiment are included as
15 Appendix B to this application. The result of the
calculation by the EMS based on the vehicle model for the
selected profile is displayed as, for example, "range
under constant speed of xx mph downhill is xxx miles."

If the driver selects from the PREDICT RANGE menu,
20 one of the memorized trips, the calculation made by the
EMS employs the stored table of energy consumption versus
time as input to the vehicle mathematical model. After
calculation, the resulting display based on the existing
battery charge would be "trip number x can be successfully
25 completed z times with yyy miles remaining." This format
allows use of the EMS system for a standard commute
allowing the driver flexibility in selecting charging
times for the vehicle.

A flow diagram of exemplary programming for operation
30 of the EMS in the PREDICT RANGE menu is shown in FIGS. 4a
and 4b. Data formats for this program sequence are shown
in the listing provided in Table 1. The EMS displays the
PREDICT RANGE menu on the text display as shown in box 410
for review by the driver. The EMS microcontroller
35 monitors the driver interface control buttons to determine
if a control button has been pressed within ten seconds as
shown by the decision block 412. If no button has been

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1 pressed, the EMS sets the mode of operation to the
non-expert (NI) mode for operation in block 413, blanks
the display 414, and enters a wait routine for 416 for
button sensing. Returning to the decision block 412 if a
5 button has been pressed, the microcontroller determines if
the ESCAPE key has been pressed, block 418. If so, the
program returns to block 412, setting the system to the NI
mode. If the ESCAPE key is not the key pressed, the
microcontroller determines if the SCROLL key has been
10 pressed in block 420. If the SCROLL key has been
depressed, the microcontroller moves to display the next
menu as identified in block 510. If the SCROLL key has
not been depressed, the EMS determines if the NUMERIC key
has been depressed in block 424. The NUMERIC key has no
15 significance in this menu pattern and if the numeric key
has been depressed, control is returned to block 412 as if
no button had been pressed. If the button pressed is the
ENTER key, by default the program proceeds to block 426
and sets the parameters i and j=0. The microcontroller
20 then displays the scrolled menus identified in Table 1 in
the form of menu (1,i) and appends the speed and units or
the trip number as shown in block 428. For example, if
the menu pointer is at menu(1,2) the display will show
"uphill at xx mph." If, however, the menu pointer is at
25 menu(1,5) the display will show "memorize trip # x."
After displaying the menu, the controller enters decision
block 430. If the second index of the menu pointer equals
one, the microcontroller proceeds to decision block 432 to
await a button press. If no button is pressed within ten
30 seconds, the microcontroller returns to entry point A at
block 413. If a button has been pressed, the
microcontroller determines if the SCROLL key is pressed in
decision block 434. If the SCROLL key has been depressed,
the second index of the menu pointer i is incremented in
35 block 436 with a counter operating modulo 7. The counting
modulus, length (x), for the various counters described
are shown in Table 1. Upon incrementing of the menu

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1 index, the program returns to entry point B at block 428
to display the new menu. If the SCROLL key was not the
button pressed, the microcontroller continues to decision
block 437 to determine if the ENTER key was pressed. If
5 the ENTER key was pressed, selecting the menu having
pointer equal 1, the driver has selected the "stop and go"
menu. In this case, the microcontroller retrieves from
memory the vehicle model and employs the SFUDS data as a
driving profile to determine vehicle range as shown in
10 block 438. Upon completion of the calculation, a display
of "stop and go range is" accompanied by the result of the
calculation and the appropriate units as shown in block
440. If no further button is pressed within ten seconds,
the program returns to entry point A as shown in block
15 442. If after the display of the stop and go answer the
ESCAPE key is pressed as detected in block 444, the
program returns to entry point B at block 428 to display
the previous menu.

If the ENTER key was not pressed, in block 436, the
20 program determines if the ESCAPE key was pressed in block
445. If the ESCAPE key was not pressed, the only key
remaining is the NUMERIC key which has no meaning for the
menu pointer of 1 since no numeric input is required by
the driver. Consequently, control is returned to block
25 432 to await an additional button press. If the ESCAPE
key has been pressed, the menu pointer is reset to 0 and
control of the program returns to entry point C.

Returning to block 430, if the second index of the
menu pointer is 0, 2, 3, or 4, additional entry for the
30 speed desired is required by the driver. Consequently,
the microcontroller waits for a button push as identified
in block 446. If a button push does not occur within ten
seconds, control of the program returns to entry point A.
If a button is pushed within ten seconds, the controller
35 determines in block 448 if the SCROLL key has been pressed
and if so, increments the menu pointer in block 450 and
returns to entry point B to display the next menu. If the

1 SCROLL key is not pressed, the controller determines if
the ENTER key has been pressed in block 452. If the ENTER
key has been pressed, the vehicle model is run using the
matrix data for required power at the speed initially
5 displayed in the menu as shown in block 454. Upon
completion of the calculation, the selected driving
profile and the range associated with that profile is
displayed as shown in block 456. For example, if the menu
pointer was 0 providing the menu selection "level at xx
10 mph" the display will show "level at xx mph range is yy
miles."

If the ENTER key was not depressed, the
microcontroller determines if the ESCAPE key was pressed
in block 458. If the ESCAPE key was pressed, the menu
15 pointer is reset to 0 and the program returns to entry
point C.

If the ESCAPE key was not pressed by default, the
pressed key was the NUMERIC key resulting in incrementing
of the numeric speed value as shown in block 460. The
20 program then returns to entry point B and the display for
the given menu pointer is again provided with the
incremented speed value.

Returning to block 430, if the second index of the
menu pointer equals 5 signifying selection of a memorized
25 trip, the program transitions to entry point D of FIG. 4b.
The microcontroller determines if a button has been
pressed in block 462 and if no button is pressed within
sixty seconds, the program returns to entry point A. If
a button has been pressed, the microcontroller determines
30 in block 464 if the ESCAPE key was pressed. If the ESCAPE
key was pressed, program control returns to entry point C.
If not, the program determines in block 466 if the NUMERIC
key was pressed. If the NUMERIC key was pressed, the
memorized trip variable j is incremented as shown in block
35 468. Incrementing of j is accomplished with a counting
modulus "memorized trips" equal to the number of segmented

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1 memory locations provided for memorizing trip data.
Control of the program then returns to entry point B.

5 If the microcontroller determines that the ENTER key
has been pressed in block 470, the identified, memorized
trip present on the display screen has been selected by
the driver and the microcontroller calculates the power
required for the identified trip as shown in block 472.
Upon completion of the calculation, the microcontroller
displays the results of the calculation in the format
10 "memorized trip number j range is yy trips plus xx miles"
as shown in block 474. Control of the program then
returns to entry point D allowing additional calculation
of memorized trip information.

Returning to decision block 430, if the second index
15 of the menu pointer equals 6, the EMS performs a data
exchange and interaction with a navigator system in block
476 to provide predictions of energy availability in the
battery system for routes defined by the navigator.
Further description of the navigator system interaction is
20 provided in detail subsequently.

The SELECT DRIVING MODE menu allows the driver to
select either a "economy," or "performance" mode for the
EMS in operation of the vehicle. Normally during driving,
the driver is not interacting with the EMS and therefore
25 the display is blank so as not to distract the driver.
The EMS is continually monitoring various inputs from the
vehicle as previously described. Inefficient energy usage
by vehicle systems monitored by the EMS can be detected.
As an example, if the microcontroller of the EMS receives
30 an input from the external temperature sensor indicating
high outside temperature and an indication from the window
position sensor that the windows are rolled down,
operation of the air conditioner in attempting to cool the
vehicle would be inefficient. In a direct control format
35 as shown in the drawings for the present embodiment, the
HVAC system controlled by the EMS through the I/O port
could be disabled until the windows are closed. In

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1 addition, (or alternatively) the EMS may display to the driver, a message "roll up windows."

In the embodiment shown in the drawings, external analog sensors, such as the temperature sensors and
5 accelerometer, are provided to the microprocessor through a multiplexed Analog to Digital input port 74 as shown in FIG. 2. Standard controls for the HVAC and motor controller as exemplary are provided through standard I/O ports 76.

10 Selection of the "performance" mode from the driving mode menu suppresses the EMS monitoring of efficiency information and precludes display of energy efficient messages to the driver. As previously described, selections in the SELECT DRIVING MODE menu are
15 accomplished by pushing the ENTER button followed by depressing the SCROLL button for selection between the sub-menu items of "economy," or "performance" followed by pushing the ENTER button to confirm the selection. In the embodiment of the present invention, the default driving
20 mode is "economy."

FIGS. 5a and 5b are a flow diagram of programming associated with the SELECT DRIVING MODE menu. The SELECT DRIVING MODE menu is displayed on the text display by the microcontroller as shown in block 510. The
25 microcontroller determines if a button has been pressed as shown in decision block 512. If no button is pressed within ten seconds, the microcontroller places the system in the nonexpert mode, blanks the display and waits for a button press as previously described with respect to FIG.
30 4a. Similarly, if the microcontroller determines in block 514 that the ESCAPE key has been pressed, exiting the SELECT DRIVING MODE menu, the microcontroller will return to its initial state.

If the SCROLL button has been pressed as shown in
35 block 516, the next menu DISPLAY VEHICLE STATUS will be displayed as shown in block 518. If the NUMERIC key is depressed as shown in block 520, the input is ignored

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1 since the NUMERIC key has no meaning at this menu level.
If by default the ENTER key has been depressed confirming
the "select driving mode" decision by the driver, the
second index of the memory pointer is set to 0 as shown in
5 block 522 and the microcontroller displays the sub-menu as
shown in block 524. The displays of the sub-menu
identified for the menu pointer having a first index 2 are
shown in Table 2.

The microcontroller again senses a button push as
10 shown in block 526 and determines if the button pressed is
the SCROLL button as shown in block 528. If the SCROLL
button has been depressed, the menu pointer is incremented
as shown in block 530 and the new sub-menu is displayed by
return through entry point X.

15 If the SCROLL key was not depressed, the
microcontroller determines if the ENTER key was depressed
in block 530. Depressing the ENTER key confirms the
selection by the driver of the displayed sub-menu and, as
shown in block 534, if the second index of the menu
20 pointer equals 0, the microcontroller establishes the
driving mode as "economy" defined in block 536. While if
the second index of the menu pointer equals 1, the
microcontroller sets the driving mode to "performance" as
shown in block 538. If the ESCAPE key has been depressed
25 as shown in block 540, the second index of the menu
pointer is reset to 0 and the program returns to entry
point X.

The DISPLAY VEHICLE STATUS menu allows the driver to
examine the status of the data inputs and outputs of the
30 EMS. For example, selecting the DISPLAY VEHICLE STATUS by
pressing the ENTER button would allow a display of inside
air temperature, outside air temperature, motor
temperature, battery pack temperature, controller
temperature, instantaneous battery pack voltage,
35 instantaneous battery pack current draw and any values
calculated by the EMS from these parameters. With the
limited display size in the present embodiment, the

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1 DISPLAY VEHICLE STATUS selection provides sub-menus with
one or more of the displayed values, e.g. "outside air
temperature is xx." Sequential display of the various
status items is accomplished by pressing the SCROLL
5 button.

The CHARGE BATTERY menu allows the driver to inform
the EMS of the desired charging time to allow optimum
charging of the battery by the EMS for that time. For
example, if the driver is running into the store for
10 groceries and the vehicle is attached to a charging
station at the store, the vehicle will only be on charge
for a few minutes. If on the other hand, the driver has
parked the vehicle in his home garage, it may be left for
a number of hours. Slow charging is easier on the battery
15 pack than fast charging. Consequently, the EMS would
direct different charging algorithms to be used depending
upon the length of time available to charge. Invoking the
CHARGE BATTERY function from the main menu by pushing
ENTER causes a prompt of "charge battery for xx hours" to
20 appear. The driver can modify the numeric value by
pressing the NUMERIC button as described previously. The
ENTER button is then pressed to establish the time
available for charging to the EMS. The EMS then selects
an appropriate algorithm based on predetermined hour
25 values and proceeds to charge the vehicle. In the present
embodiment, if a particular time is not established by the
driver through the use of this function, the EMS will
employ an algorithm based upon the optimum charging
efficiency for the present state of the battery.

30 As shown in FIG. 3a, subsequent to establishing the
charging procedure through the CHARGE BATTERY menu, the
EMS provides a VEHICLE ON CHARGE menu 332 for providing
information on the battery charging status. In addition,
upon completing the battery charging cycle, a CHARGE
35 COMPLETED menu 334 is provided for notification of the
driver of a charge and battery status prior to reentering
the MAIN DISPLAY menu.

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1 As previously described, the expert menu functions
entered through the EXPERT menu 322 allow modification and
control of the EMS by the driver. The SET TIME menu is
self explanatory and allows the driver to update the EMS
5 system with current time and date. The CHANGE DISPLAY
menu allows sub-menus of SELECT LANGUAGE and SELECT UNITS.
The SELECT LANGUAGE menu in the E mode causes a series of
languages to appear one at a time on the display. The
driver selects the desired language for use on the EMS
10 displays by pressing the SCROLL button and confirming the
choice with the ENTER button. The information on language
choice is saved in the NVRAM and the chosen language is
used until changed by an alternate selection using the
CHANGE DISPLAY menu. All messages described in the
15 various menu functions are encoded in all languages
available. These messages are stored in the
microcontroller ROM. The SELECT UNITS function of the
change display menu operates in the same manner as the
SELECT LANGUAGE function to allow selection of English or
20 metric units for display. For example, selection of the
English system will display miles and miles per hour,
while the metric display will display kilometers and
kilometers per hour.

 The CHANGE BATTERY MODEL and CHANGE CHARGING
25 ALGORITHM functions are provided to allow modification of
the numeric parameters for changes of battery types, aging
of the batteries and other altered operating parameters
for the vehicle.

 The final menu provided in the E mode is the MEMORIZE
30 TRIP menu. This function is selected by the driver to
memorize the energy consumption of a particular trip which
will be accomplished on a repetitive basis to allow
prediction by the EMS for successfully accomplishing that
trip with existing battery charge. Upon selection of the
35 memory function, the display shows "memorize trip number
x'." If the driver now pushes the ENTER button, the EMS
will ask for an indication of when to start memorizing

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1 battery power consumption data. This is accomplished by
displaying "memorizing trip number x" and, on the next
line of the display, "start" indicating that the next
depression of the ENTER button will cause the EMS to begin
5 memorizing energy consumption. During memorization, the
power drain by the vehicle is sampled periodically (in the
present embodiment, once per second). This power
requirement is saved in a table along with the amount of
time this amount of power was required. The power is
10 determined by monitoring the battery pack current and
voltage and calculating a product of the instantaneous
values. Once the enter button is pushed and the
memorization is in progress, the word "start" is replaced
on the display by the word "stop" indicating that a
15 subsequent push of the ENTER button will cause the
memorization to stop. A variation on this process is
accomplished if the trip number x has already been
memorized. If the driver selected that trip number, the
EMS assumes that the driver wishes to replace the
20 information previously memorized by information for a new
trip. In this case, the display shows "replacing trip
number x" along with the start or stop indications. In
the present embodiment, up to nine trips can be memorized.
Whenever a trip is memorized, the resulting data table of
25 energy consumption allows range prediction without
requiring calculation based on the vehicle model. Since
the energy consumption for the trip is already known,
prediction is accomplished by subtracting the energy
consumption from the available energy in the battery pack
30 for each time step of the table. The tabular information
for the memorized trips is stored in the NVRAM.
Limitations on the number of stored trips is imposed by
memory size.

Details of the overhead for the operating system of
35 the microcontroller in the present invention are shown in
FIGS. 6a and b and 7a-e. The microcontroller for the
present embodiment initiates operation with a system reset

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1 610 as shown in FIG. 6a. Interrupts are disabled 612
while initialization of the input output ports 614 is
accomplished. As previously described with respect to
FIG. 2, the I/O ports 76 provide the data paths for
5 communication between the microcontroller and the ignition
switch, instrument panel 45 (comprising the various
display elements including the speedometer, odometers,
fuel gauge and charge and reserve icons), the HVAC
controller and the motor controller.

10 After initialization of the I/O ports, the serial
port interrupt (PTS) is enabled for communication through
serial port 64 and of FIG. 2. The microcontroller
communicates with the battery monitor module through the
serial port providing a "cancel charge packet" data block
15 to the self contained battery monitor module as a reset.
See block 618. The microcontroller then blanks the text
display through serial port 70 and the instrument panel
through the I/O ports. See block 620.

The microcontroller next enables the software timer
20 interrupts 622 to allow interface with the clock circuit
78 of FIG. 2 for generalized program clocking. The speed
sensor interrupt is enabled 624 for communication with the
speed sensor. In the present embodiment, the speed sensor
comprises a slotted wheel 80 shown in FIG. 2 located on a
25 drive axle of the vehicle, an IR light emitting diode 82
providing an illumination source through fiber optic cable
to one side of the slotted wheel and an IR detector 84
connected through fiberoptic cable receiving signal from
the opposite side of the slotted wheel. The signal from
30 the IR detector, representative of the rotational speed of
the axle, is provided to an interrupt port 86 in the
microcontroller.

The microcontroller enables the speed calculation
interrupt 626 as a final preoperation function.

35 The microcontroller senses the status of the vehicle
ignition switch in decision block 628. If the switch is
not "on" indicating desire for operation of the vehicle by

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1 the driver (or turning off of the ignition switch since
the last calculation cycle) the microcontroller continues
to blank the instrument panel and EMS text display as
shown in block 630. Upon sensing that the ignition switch
5 has been turned on, the microcontroller determines in
block 632 if the ignition switch was previously "off". If
the ignition switch was previously "off", the
microcontroller performs an instrument panel and EMS
startup display 634 and performs a system check 636 to
10 detect hardware faults. If no fault is detected in block
638, the microcontroller sets the text display to the main
menu previously described with respect to FIG. 3 in block
640. If a system fault was detected, the fault is
reported 642 by appropriate annotation of the text
15 display.

Upon completion of the startup sequence, or if the
ignition switch was not previously "off", the
microcontroller displays the instrument panel and EMS
information 644 corresponding to the various sensor
20 inputs. The microcontroller monitors the control buttons
to determine if a button has been pressed 646 and if the
SCROLL button has been pressed, highlights the action
following the presently highlighted action on the menu 648
to scroll through the menus as previously described with
respect to FIGS. 3, 4, and 5. If the ENTER key has been
25 pressed, the microprocessor performs the highlighted
action and designates the appropriate menu for the
highlighted action as active 650, also previously
described with respect to FIGS. 3, 4 and 5. If the
30 NUMERIC key has been pressed, the microprocessor
determines if a numeric variable is highlighted in the
menu 652. If no numeric variable is highlighted,
depressing the NUMERIC key has no function. A system
check for faults is accomplished 654 and if a system fault
35 is detected 656, the system reports the fault 658, program
control then returns to block 628.

1 If a numeric variable is highlighted in block 652 and
the NUMERIC key is pressed, the highlighted numeric
variable is incremented by the count modulus 660 as
previously described with respect to FIGS. 4 and 5.

5 If the ESCAPE key is pressed, the microprocessor sets
the active menu to the menu above the present active menu
on the menu hierarchy list in block 662 as previously
described with respect to FIGS. 3, 4 and 5.

10 If the SCROLL and ENTER keys are depressed
simultaneously, the microcontroller sets the active menu
as the EXPERT MODE menu as shown in block 664 and
previously described with respect to FIG. 3.

15 All other functions of the microcontroller are
initiated through the interrupt processor on a timed or
demand basis. Exemplary interrupt routines for the
microcontroller are shown in FIG. 7. The software timer
update interrupt routine occurs periodically as shown in
FIG. 7a. Upon receiving this interrupt, the
microcontroller determines if the speed sensor needs to be
20 enabled in block 710. The speed sensor interrupt is
disabled in various other interrupt routines as will be
described subsequently. If the speed sensor interrupt has
been disabled, the microcontroller enables the PTS speed
sensor interrupt 712 and enables the speed calculation
25 interrupt 714 to allow normal processing of speed
information for update of the display on the instrument
panel speedometer and odometers.

30 The microcontroller next conducts the Analog to
Digital conversion of analog sensor data input in block
716. Results of the sensor inputs are stored in memory
block 718 to update the VEHICLE SYSTEM STATUS menu for
display upon demand as described with respect to FIG. 3.
Updated information is output to the instrument panel
displays by the microcontroller in block 720. The
35 microcontroller then returns to the interrupt wait state.

Calculation of vehicle speed and distance traveled
for display on the speedometer and odometers of the

1 instrument panel is accomplished employing interrupt
routines for speed calculation and the speed sensor PTS
interrupt as shown in FIGS. 7b and 7c. In the present
embodiment, interrupt signals received from the IR
5 detector of the speed sensor are accumulated and timed
based on a predetermined PTS count. As shown in FIG. 7b,
upon receiving an interrupt from the IR detector, the
microcontroller decrements the PTS count 722 and
determines if the PTS count is now 0 in block 724. If the
10 PTS count is 0, the PTS interrupt is disabled 726 to allow
a time speed calculation to occur in response to a speed
calculation interrupt. The time of the PTS interrupt from
the speed sensor is recorded 728 and stored for speed
calculation. A return is then executed from the interrupt
15 handler.

Speed calculation is accomplished upon receiving a
speed calculation interrupt as shown in FIG. 7c. Speed
calculation is accomplished by determination of the total
elapsed time for the PTS count cycle of the speed sensor
20 interrupts from the recorded time intervals in block 730.
The total odometer and trip odometer are updated in block
732 and 734 respectively and the PTS count is reset in
block 736 for initializing the speed sensor interrupt.
The speed calculation interrupt is disabled 738 to
25 preclude a speed calculation interrupt prior to
initialization of the speed sensor PTS interrupts through
the software timer update interrupt routine as previously
described. A return from the interrupt handler is then
executed.

30 Data from the battery monitor module is received on
the serial port as previously described. Incoming data is
accepted through a serial port receive interrupt as
described in FIG. 7d. Data transmitted from the battery
monitor module is provided in a predefined format for
35 verification of valid data which is accomplished in block
740. If the data received is not valid as determined in
block 742, a tabulation of the number of errors is

1 incremented in block 744. If the number of errors
detected is less than 10, as determined in block 746, the
error is ignored and a return is executed from the
interrupt handler. If the number of errors has reached
5 10, the microcontroller reports the error through the EMS
text display as shown in block 748 to notify the driver of
a battery monitor module failure.

If valid data is received from the battery monitor
module, a new "fuel" status is calculated in block 750 to
10 determine power remaining in the battery. Parameters for
the battery model are then updated in block 752 for use in
vehicle model calculations as previously described. The
error monitor flag is then reset to 0 in block 754. A
determination is made in block 756 if an updated message
15 to the EMS display is required. For example, if the menu
on the display is the vehicle on charge menu as previously
described with respect to FIG. 3, a change in the battery
status would be reflected on the menu. The
microcontroller alters the display message as shown in
20 block 758, if required, and the interrupt handler is reset
in block 760 for return to the wait mode.

The software timer clock interrupt is accomplished as
shown in FIG. 7e to accomplish updating of the system
clock 762 and transfer of any battery management system
25 data to the battery monitor module through the serial
port. As previously described, the battery monitor module
in the present embodiment is a self-contained unit,
consequently, data is provided in a packet format executed
by the microcontroller as shown in block 764. An example
30 of data transmissions of this type would be associated
with charging of the battery wherein control of the
charging current and voltage by the battery monitor module
is accomplished to charge the battery according to the
desired charging algorithm as previously described.

35 Upon completion of the software timer clock
interrupt, the microcontroller returns to the wait state
from the interrupt handler.

1 The EMS in combination with a vehicle navigator
system provides further expanded capability for efficient
operation of the electric vehicle. Navigator systems,
such as those disclosed in U.S. Patent No. 4,926,336 to
5 Yamada provide a database typically including street
names, street segment x and y coordinates, street segment
end addresses and assumed street segment speeds for a
given mapped area. The basic purpose of a navigator is to
provide an optimum route to be driven based on a starting
10 point and a destination point. The present embodiment
adds to the navigator database street segment grade and
direction of grade, stop sign and traffic light locations
and location of charging stations for electric vehicles.
Associated with the traffic light data is a probability of
15 a green light for each direction of traffic in the control
intersection. Dynamic information on traffic congestion
for given street segments is provided through a radio
interface.

FIG. 8 provides a basic block diagram of the
20 interface between the navigator and EMS. The navigator
810 is a self-contained system employing a database 812
having the characteristics previously described and a
radio interface 814. The navigator incorporates a
calculation engine 816 for determining routes between an
25 entered beginning point and a desired destination point.
A standard serial port interface 818 employing RS232 or
other standard communication protocol connects the
navigator to the EMS. A third serial port 88 as shown in
FIG. 2 is employed by the microcontroller for
30 communication with the navigation system.

In operation, the driver provides present position
and destination information to the navigator system. The
navigator selects several time efficient routes using
normal processing models, as described in the prior art.
35 These routes are likely to be the most energy efficient,
however, iteration between the navigator and EMS is
required for optimizing energy efficiency of the route.

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1 The data information for the route selected by the
navigator is communicated to the EMS over the serial link.
A protocol of the present embodiment provides for
transmission of each street segment in following format:
5 Send start of segment character (e.g., "S"); send length
of segment (e.g., xx miles); send indication of stop at
start of segment (e.g., "X"); send grade of segment (e.g.,
xx%); send direction of grade (e.g., "U" or "D" for up or
down); send nominal speed of segment (e.g., xx
10 miles/hour); and, send end of message character (e.g.,
"E"). The energy usage for the individual segment is
calculated by the EMS employing the vehicle model and
standard prediction algorithms previously described. For
example, if the segment is an upward grade, with an
15 average speed of 30 mph, the processing algorithm for the
"uphill at xx mph" previously described with regard to the
predict range menu is employed. A start or stop on the
segment is accommodated by the EMS through a calculation
scheme defining a predetermined acceleration or
20 deceleration based on the nominal speed of the segment.
For example, if the average speed of the segment is low,
acceleration of .1 g is employed, while if average speed
of the segment is high, an acceleration of .25 g is
employed. Stopping at a constant deceleration of .5 g is
25 employed.

The EMS will calculate the energy consumption as
watt-hours for the entire trip defined by the navigator
segment by segment. If the trip can be made on the energy
available in the battery pack, the EMS reports the energy
30 consumption for the trip. The navigator and EMS iterate
with regard to the other candidate routes for optimizing
the energy usage.

If the energy required for the trip will exceed the
available battery energy, the EMS identifies to the
35 navigator the street segment indicating where the vehicle
will "run out" of energy. The navigator will then employ
an alternate route scheme for identifying a destination

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1 with a charging station with a lower mileage requirement
than the energy exhaustion point. Calculation of the
route to the charging station with verification by
iteration of the route with the EMS for energy consumption
5 calculation is accomplished. Calculation of a route from
the charging station to the original destination is then
accomplished by the navigator. Calculation of this route
requires input by the driver for the charging time to be
employed at the charging station. Calculation of the
10 energy level in the battery after the proposed charging is
accomplished using the battery model as previously
described.

Operation of the EMS in the "performance" mode allows
elimination of iteration on the routes selected by the
15 navigator and the most time efficient route selected by
the navigator is employed for calculation of capability
for the vehicle to accomplish the route on the given
energy charge in the battery.

FIGs. 9a and 9b are flow diagrams describing the
20 hand-shake operation between the EMS and navigator systems
in the electric vehicle. As shown in FIG. 9a, upon entry
by the driver of a present position and destination point,
the navigator establishes a candidate route as shown in
block 910. The navigator sends a ready-to-transmit signal
25 to the EMS 912 which is received by the EMS in block 914
of FIG. 9b. The EMS responds by sending a ready-to-
receive signal 916 which is received by the navigator in
block 918 of FIG. 9a. The navigator proceeds to send
route information 920 on a segment-by-segment basis to the
30 EMS which receives the route information 922 and runs the
vehicle model 924 to establish energy usage. The EMS
determines if sufficient energy is remaining to complete
the route proposed by the navigator. If sufficient energy
remains an energy consumed value is provided to the
35 navigator in block 928 which is received as a response by
the navigator in block 930. If sufficient energy does not
remain in the battery pack, the EMS provides a pointer to

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1 the last successful route segment 932 provided as the
response to the navigator. Upon completion of the
interaction between the EMS and the navigator, the EMS
returns to standard EMS functions 934. The information
5 concerning energy consumption or pointer for last
successful route segment received by the navigator is
analyzed in block 936. If sufficient energy is available
for the route, additional candidate routes are evaluated
and a selection of the most energy efficient route is made
10 by the navigator software in block 938. If insufficient
energy is available for any of the chosen routes, the
navigator establishes a route to a charger station nearest
the last successful route segment and employing the
charger location as an initial position calculates routes
15 to the desired destination based on driver input as to
charging time in block 940. The final route is then
communicated to the driver by the navigator in block 942.

Table 1

Coded into the program:

20 min speed = 20
max speed = 80

menu (1,0) = "LEVEL AT"	menu (2,0) = "ECONOMY"
(1,1) = "STOP AND GO"	(2,1) = "PERFORMANCE"
(1,2) = "UP HILL AT"	
(1,3) = "DOWN HILL AT"	
25 (1,4) = "UP AND DOWN AT"	
(1,5) = "MEMORIZE TRIP #"	
(1,6) = "NAVIGATOR PREDICTION"	

length (1) = 7
(3) = 1

30 Set by default or previous driver interaction:

Speed = 30
Units = "MPH"
Memorized trips = 3

35

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TABLE 2

1

Simplified FUDS (SFUDS) with velocity slightly changed
 cycle time including rest, (s), TC= 360
 rest time at end of cycle, (s), TREST = 0
 s-by-s velocity, (km/h), for TC-TREST s

5	.000000E+00	.000000E+00	.000000E+00	.000000E+00	.000000E+00
	.000000E+00	.000000E+00	.000000E+00	.000000E+00	.000000E+00
	.000000E+00	.000000E+00	.000000E+00	.000000E+00	.000000E+00
	.000000E+00	.240000E+01	.480000E+01	.720000E+01	.970000E+01
	.111000E+02	.122000E+02	.134000E+02	.146000E+02	.158000E+02
	.169000E+02	.179000E+02	.187000E+02	.195000E+02	.201000E+02
10	.208000E+02	.214000E+02	.220000E+02	.227000E+02	.233000E+02
	.240000E+02	.245000E+02	.249000E+02	.256000E+02	.261000E+02
	.275000E+02	.290000E+02	.303000E+02	.315000E+02	.328000E+02
	.340000E+02	.351000E+02	.360000E+02	.370000E+02	.378000E+02
	.388000E+02	.396000E+02	.378000E+02	.359000E+02	.341000E+02
	.320000E+02	.301000E+02	.277000E+02	.253000E+02	.227000E+02
15	.171000E+02	.114000E+02	.580000E+01	.200000E+00	.000000E+00
	.000000E+00	.000000E+00	.000000E+00	.000000E+00	.000000E+00
	.000000E+00	.000000E+00	.000000E+00	.000000E+00	.000000E+00
	.000000E+00	.240000E+01	.480000E+01	.720000E+01	.970000E+01
	.111000E+02	.122000E+02	.134000E+02	.146000E+02	.158000E+02
	.169000E+02	.179000E+02	.187000E+02	.195000E+02	.201000E+02
	.208000E+02	.214000E+02	.220000E+02	.227000E+02	.233000E+02
20	.240000E+02	.245000E+02	.249000E+02	.256000E+02	.261000E+02
	.275000E+02	.290000E+02	.303000E+02	.315000E+02	.328000E+02
	.340000E+02	.351000E+02	.360000E+02	.370000E+02	.378000E+02
	.388000E+02	.396000E+02	.378000E+02	.359000E+02	.341000E+02
	.320000E+02	.301000E+02	.277000E+02	.253000E+02	.227000E+02
	.171000E+02	.114000E+02	.580000E+01	.200000E+00	.000000E+00
25	.000000E+00	.000000E+00	.000000E+00	.000000E+00	.000000E+00
	.000000E+00	.000000E+00	.000000E+00	.000000E+00	.000000E+00
	.000000E+00	.240000E+01	.480000E+01	.720000E+01	.970000E+01
	.111000E+02	.122000E+02	.134000E+02	.146000E+02	.158000E+02
	.169000E+02	.179000E+02	.187000E+02	.195000E+02	.201000E+02
	.208000E+02	.214000E+02	.220000E+02	.227000E+02	.233000E+02
	.240000E+02	.245000E+02	.249000E+02	.256000E+02	.261000E+02
30	.275000E+02	.290000E+02	.303000E+02	.315000E+02	.328000E+02
	.340000E+02	.351000E+02	.360000E+02	.370000E+02	.378000E+02
	.388000E+02	.396000E+02	.378000E+02	.359000E+02	.341000E+02
	.320000E+02	.301000E+02	.277000E+02	.253000E+02	.227000E+02
	.171000E+02	.114000E+02	.580000E+01	.200000E+00	.000000E+00
35	.000000E+00	.000000E+00	.000000E+00	.000000E+00	.000000E+00
	.000000E+00	.000000E+00	.000000E+00	.000000E+00	.000000E+00
	.000000E+00	.240000E+01	.480000E+01	.720000E+01	.970000E+01
	.111000E+02	.122000E+02	.134000E+02	.146000E+02	.158000E+02

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1	.169000E+02	.179000E+02	.187000E+02	.195000E+02	.201000E+02
	.208000E+02	.214000E+02	.220000E+02	.227000E+02	.233000E+02
	.240000E+02	.245000E+02	.249000E+02	.256000E+02	.261000E+02
	.266000E+02	.270000E+02	.274000E+02	.278000E+02	.283000E+02
	.288000E+02	.293000E+02	.296000E+02	.301000E+02	.304000E+02
5	.309000E+02	.312000E+02	.362000E+02	.407000E+02	.447000E+02
	.483000E+02	.513000E+02	.543000E+02	.571000E+02	.597000E+02
	.621000E+02	.644000E+02	.666000E+02	.681000E+02	.695000E+02
	.708000E+02	.721000E+02	.732000E+02	.744000E+02	.755000E+02
	.766000E+02	.777000E+02	.787000E+02	.797000E+02	.806000E+02
	.814000E+02	.824000E+02	.832000E+02	.840000E+02	.848000E+02
10	.855000E+02	.863000E+02	.869000E+02	.875000E+02	.861000E+02
	.847000E+02	.832000E+02	.818000E+02	.803000E+02	.789000E+02
	.774000E+02	.760000E+02	.745000E+02	.731000E+02	.718000E+02
	.703000E+02	.689000E+02	.676000E+02	.663000E+02	.649000E+02
	.650000E+02	.653000E+02	.655000E+02	.657000E+02	.660000E+02
	.661000E+02	.663000E+02	.665000E+02	.668000E+02	.669000E+02
	.671000E+02	.673000E+02	.674000E+02	.676000E+02	.678000E+02
15	.679000E+02	.681000E+02	.682000E+02	.684000E+02	.686000E+02
	.687000E+02	.689000E+02	.689000E+02	.690000E+02	.692000E+02
	.694000E+02	.695000E+02	.695000E+02	.697000E+02	.698000E+02
	.698000E+02	.700000E+02	.687000E+02	.673000E+02	.660000E+02
	.645000E+02	.632000E+02	.618000E+02	.604000E+02	.591000E+02
	.576000E+02	.562000E+02	.547000E+02	.533000E+02	.518000E+02
20	.502000E+02	.488000E+02	.472000E+02	.457000E+02	.441000E+02
	.423000E+02	.406000E+02	.388000E+02	.370000E+02	.352000E+02
	.333000E+02	.312000E+02	.291000E+02	.267000E+02	.243000E+02
	.216000E+02	.182000E+02	.142000E+02	.930000E+01	.450000E+01
	.000000E+00	.000000E+00	.000000E+00	.000000E+00	.000000E+00
	.000000E+00	.000000E+00	.000000E+00	.000000E+00	.000000E+00
25	.000000E+00	.000000E+00	.000000E+00	.000000E+00	.000000E+00

30

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1 Having now described the invention in detail as
required by the patent statute, those skilled in the art
will recognize modifications and substitutions to the
embodiment disclosed herein. ✓ Such modifications and
5 substitutions are within the scope and intent of the
invention as defined in the following claims.

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APPENDIX A

Power requirement at the battery terminals can be calculated from a specified velocity profile, provided that the vehicle characteristics (test weight, frontal area, drag coefficient, rolling resistance coefficients, the drivetrain efficiency, and the grade of the road) are given.

The instantaneous road-load power is calculated from the required force, which overcomes the drag force, the rolling resistance, and the grading effects while, at the same time, maintaining the vehicle at the specified speed. The equations for velocity, force, and power are given below.

The instantaneous speed of the vehicle at time t in any linear driving period can be expressed as:

$$V = V_1 + a\Delta t \quad (A.1)$$

where:

- a = acceleration or deceleration
 $= (V_2 - V_1) / (t_2 - t_1)$;
- V_1, V_2 = the speed at time t_1 and t_2 respectively;
- $\Delta t = t - t_1$;
- t = time;
- t_1 = the time at the beginning of the period; and
- t_2 = the time at the end of the period.

The distance at time t is given by:

$$S = S_1 + v_1 \Delta t + \frac{a}{2} (\Delta t)^2 \quad (A.2)$$

where S_1 is the distance at t_1 .

As shown in FIG. A.1, the total required driving force, F_T , is given by:

$$F_T = F_D + F_R + F_G + F_A \quad (A.3)$$

with the air-drag force,

$$F_D = \frac{1}{2} \rho C_D A_F V^2 \quad (A.4)$$

the rolling resistance force,

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$$F_R = W_T \cos \theta (K_0 + K_1 V + K_2 V^2) \quad (A.5)$$

the force due to grade,

$$F_G = W_T \sin \theta \quad (A.6)$$

and the acceleration force,

$$F_A = \frac{W_T}{g} a \quad (A.7)$$

where:

W_T = vehicle weight;
 g = gravitational acceleration;
 θ = grading angle, $\tan^{-1} (\% \text{ grade}/100)$;
 K_0, K_1, K_2 = rolling resistance coefficients;
 A_F = vehicle frontal area;
 ρ = air density; and
 C_D = drag coefficient

The power at the wheels, P_{wh} , is given by:

$$P_{wh} = V F_T \quad (A.8)$$

and the power required at the battery terminals is:

$$P_\beta = \frac{P_{wh}}{\eta_D \eta_M} \quad (A.9)$$

where:

η_D and η_M are efficiencies of the transmission and the motor, respectively.

1. In the present embodiment, rather than using a constant, a function of rpm and torque is used. Thus $\eta_M = \eta_M(\text{rpm}, T)$ locating a table

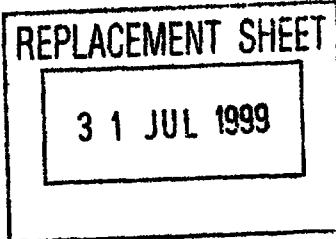
	T	T_1	T_2	T_3	T_4
RPM					
R_1	η_{11}	η_{12}			
R_2	η_{21}				
R_3	$\vdots$				
R_4	$\vdots$				
$\vdots$	$\vdots$				

lation of this table is employed to get N (rpm, torque).

2. Also in the present embodiment, rather than using a constant, a function of rpm is used. Thus $\eta_D = \eta_D(\text{rpm})$. We have a table

<i>RPM</i>	η_D
R_1	η_1
R_2	η_2
R_3	η_3
$\vdots$	$\vdots$

interpolation of this table is employed to get $\eta_D(\text{rpm})$.



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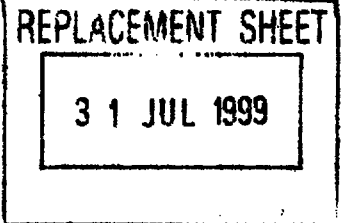
APPENDIX B

EXAMPLE OF BATTERY DATA

TABLE D.1 Default Data Set for Sodium/Sulfure Batteries,
1988 Technology ✓

Na/S battery - 1988 Technology: CSPL 24-cell module

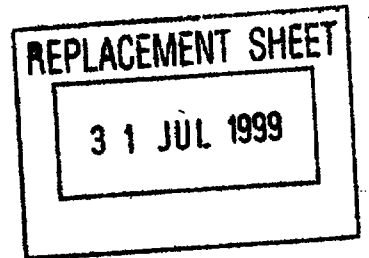
wt. of a battery cell, (kg), WC =	.120000E+00	
accessory wt./cell, (kg), WY =	.600000E-01	
no. of parallel strings, NPS =	.300000E+02	
cell amp-hours @ C/3, C3 =	.833000E+01	
cell cutoff voltage comp.1, DCOV1 =	.190000E+01	
cell cutoff voltage comp.2, DCOV2 =	.397500E+01	
no. of (DOD, NLV) data pairs =		9
.000	2.050	
.050	2.070	
.100	2.080	
.400	2.080	
.500	2.070	
.600	2.068	
.700	2.055	
.800	2.035	
1.000	1.935	
no. of (DOD,R) data pairs =		8
.000	.495E-01	
.050	.383E-01	
.100	.371E-01	
.200	.371E-01	
.400	.383E-01	
.600	.404E-01	
.900	.457E-01	
1.000	.468E-01	
Regen (DOD,NLV) data pairs =		5
.000	2.080	
.250	2.070	
.500	2.060	
.750	2.050	
1.000	1.950	
Regen (DOD,R) data pairs =		5
.000	.350E-01	
.250	.370E-01	
.500	.370E-01	
.750	.380E-01	
1.000	.780E-01	
battery parameter, G1 =		.000000E-00



What is Claimed Is:

1. An energy management system, for vehicles employing a limited energy storage system, comprising:
means for receiving power status data from the
5 energy storage system;
means for storing a plurality of driving profile data sets;
selection means for selection by the driver of one of said driving profiles;
10 - calculation means connected to the receiving means and storage means for calculating energy storage system exhaustion based on the selected driving profile; and,
output means to display the energy storage
15 system exhaustion calculation to the driver.
2. An energy management system as defined in claim 1 wherein the driving profiles include predetermined data for standard driving modes.
20
3. An energy management system as defined in claim 1 wherein the driving profiles include data supplied by a vehicle navigator for route segments between a present position and a desired destination.
25
4. An energy management system as defined in claim 1 further comprising means for storing energy storage system status data from the receiving means as a function of time and wherein the driving profiles include memorized
30 energy storage system power consumption data stored by the energy storage system data storage means.
5. An energy management system as defined in claim 1 wherein the energy storage system comprises a battery,
35 further comprising controllable means for charging the battery and wherein the calculation means includes means for determining a battery charging profile based on the





energy storage system status data and means for controlling the charging means to match the charging profile.

- 5 6. An energy management system as defined in claim 1 wherein the output means comprises a menu-driven display and the selection means comprises interactive selection keys for the menu.
- 10 7. An energy management system as defined in claim 1 further comprising vehicle system status sensors receiving data on parameters effecting energy consumption by the vehicle, said sensors connected to the calculation means and wherein the calculation means includes means for
- 15 comparing sensor inputs for detection of inefficient energy consumption and means for displaying on the output means such identified inefficiencies.
- 20 8. An energy management system as defined in claim 7 further comprising control means for disengaging vehicle subsystems and wherein the calculation means further comprises means for activating the control means responsive to detected energy inefficiency.
- 25 9. An energy management system as defined in claim 1 wherein the energy storage system comprises multiple storage elements with differing rates of charge and discharge, further comprising means for controllably directing regenerated energy from braking of the vehicle
- 30 to a selected one of the storage systems and wherein the calculation means includes means for controlling the directing means.



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ENERGY MANAGEMENT SYSTEM FOR VEHICLES HAVING LIMITED
ENERGY STORAGE

Abstract

The Energy Management System comprises an electronic module 10 which incorporates a microcontroller 12 as a calculation engine and means for controlling various systems of an electric vehicle or other vehicle having limited energy storage. A variety of sensors including battery sensors 18, temperature sensor 20, current sensor 22, temperature sensors 24, 26, 28, 30, speed sensor 32, accelerometer 34, and ignition switch 36 provide information for the Energy Management System to derive control parameters for the systems. Automatic control of heating and air conditioning system 56, external lighting system 58 and the operation of motor controller 54 as well as display of information, status and queries to the driver are controlled by the Energy Management System and range and navigation recommendations are made based on predefined driving profiles maintained in the system.

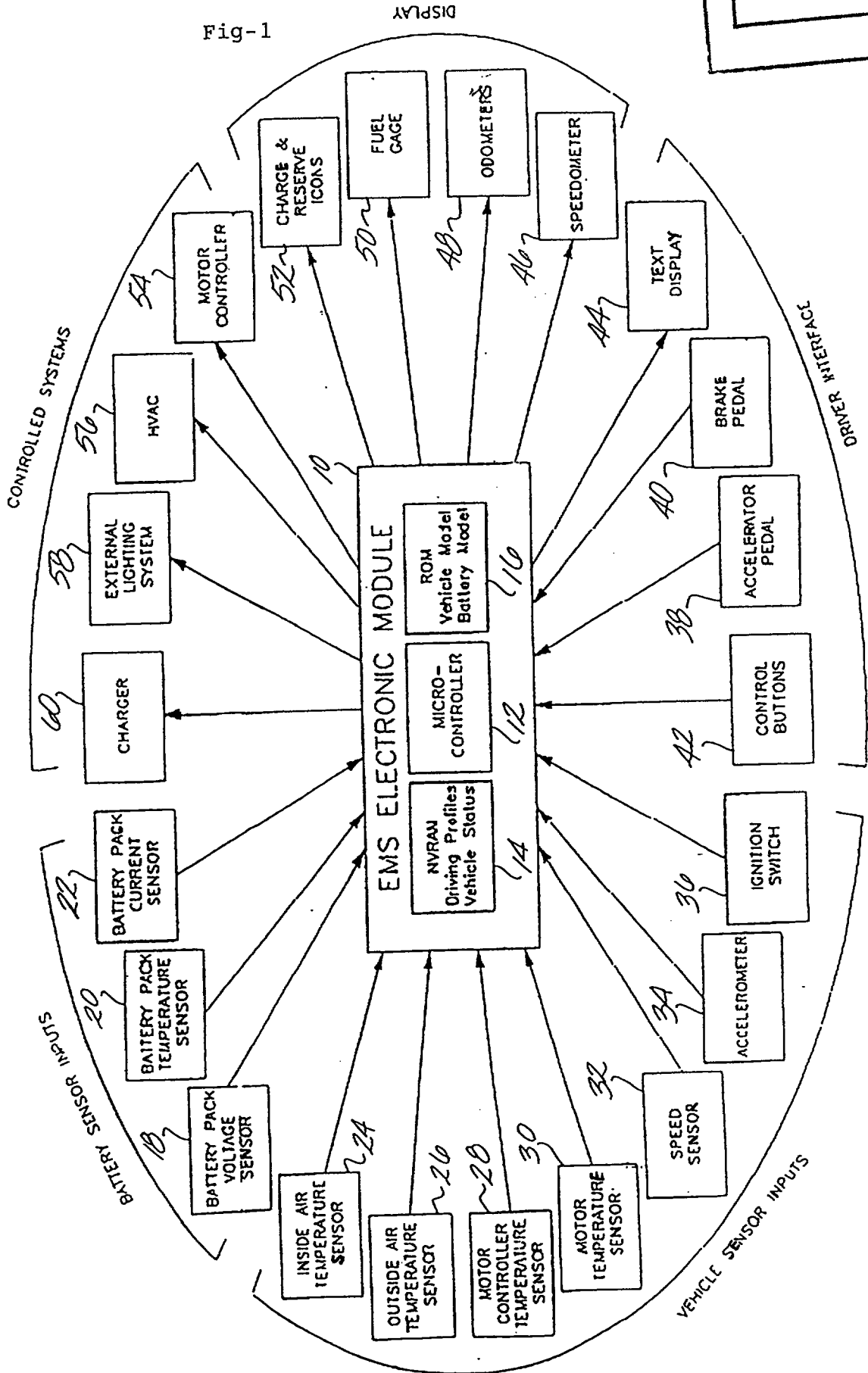
Figure 1

This Sheet Has Been Replaced



REPLACEMENT SHEET
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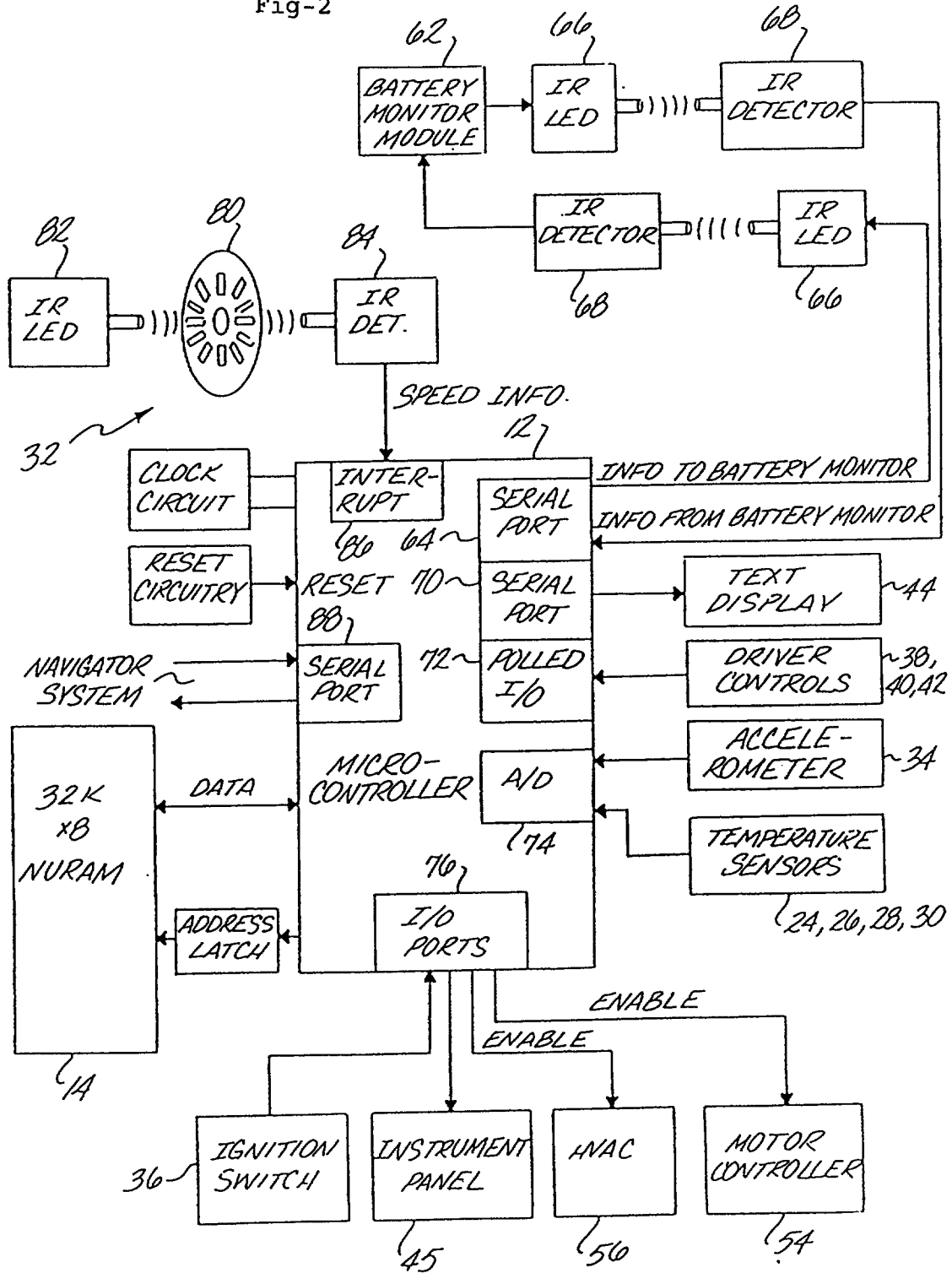
Fig-1



REPLACEMENT SHEET

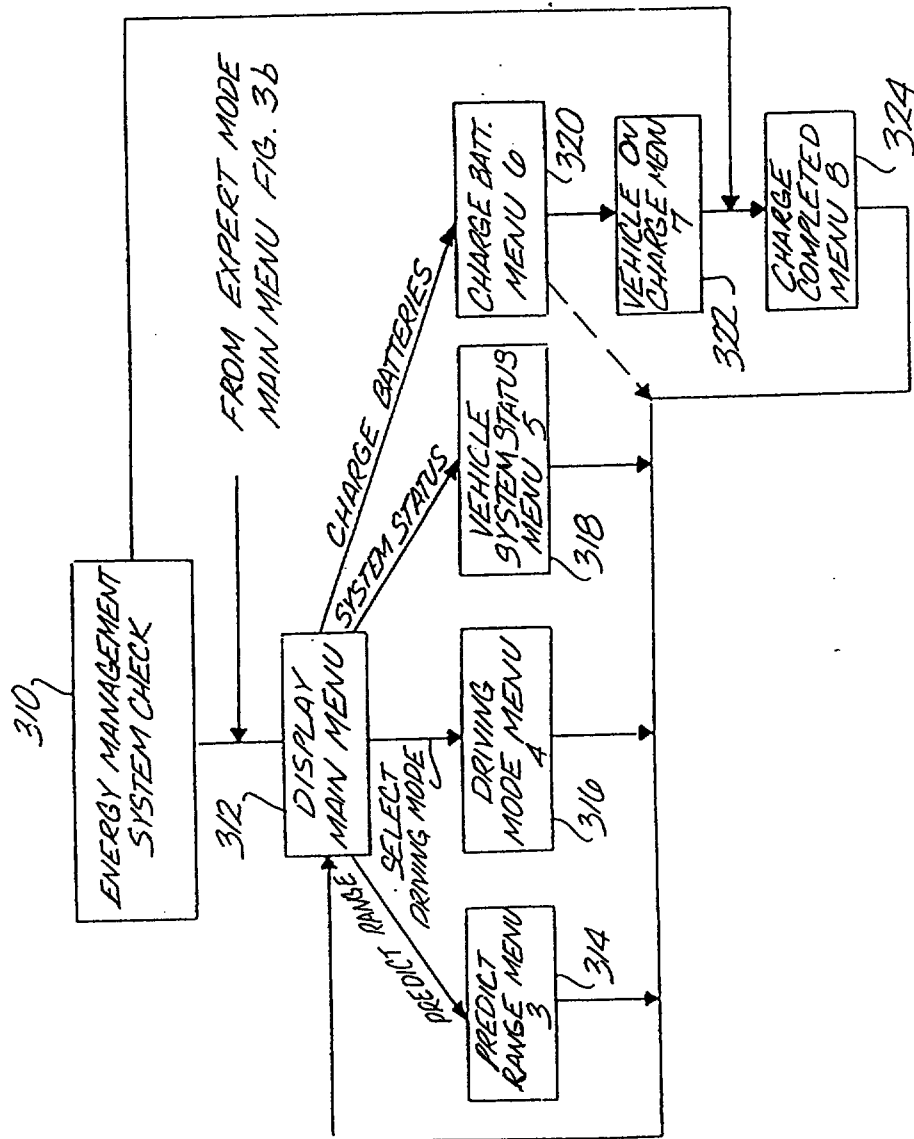
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Fig-2



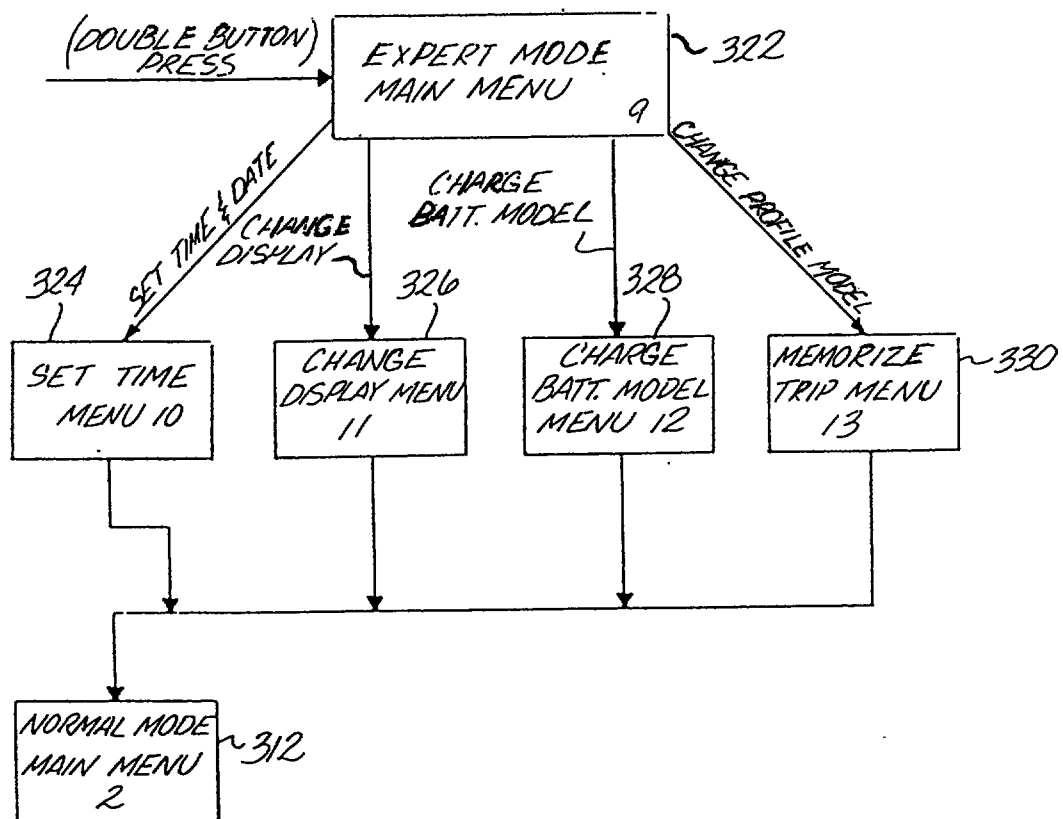
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Fig-3a



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Fig-3b



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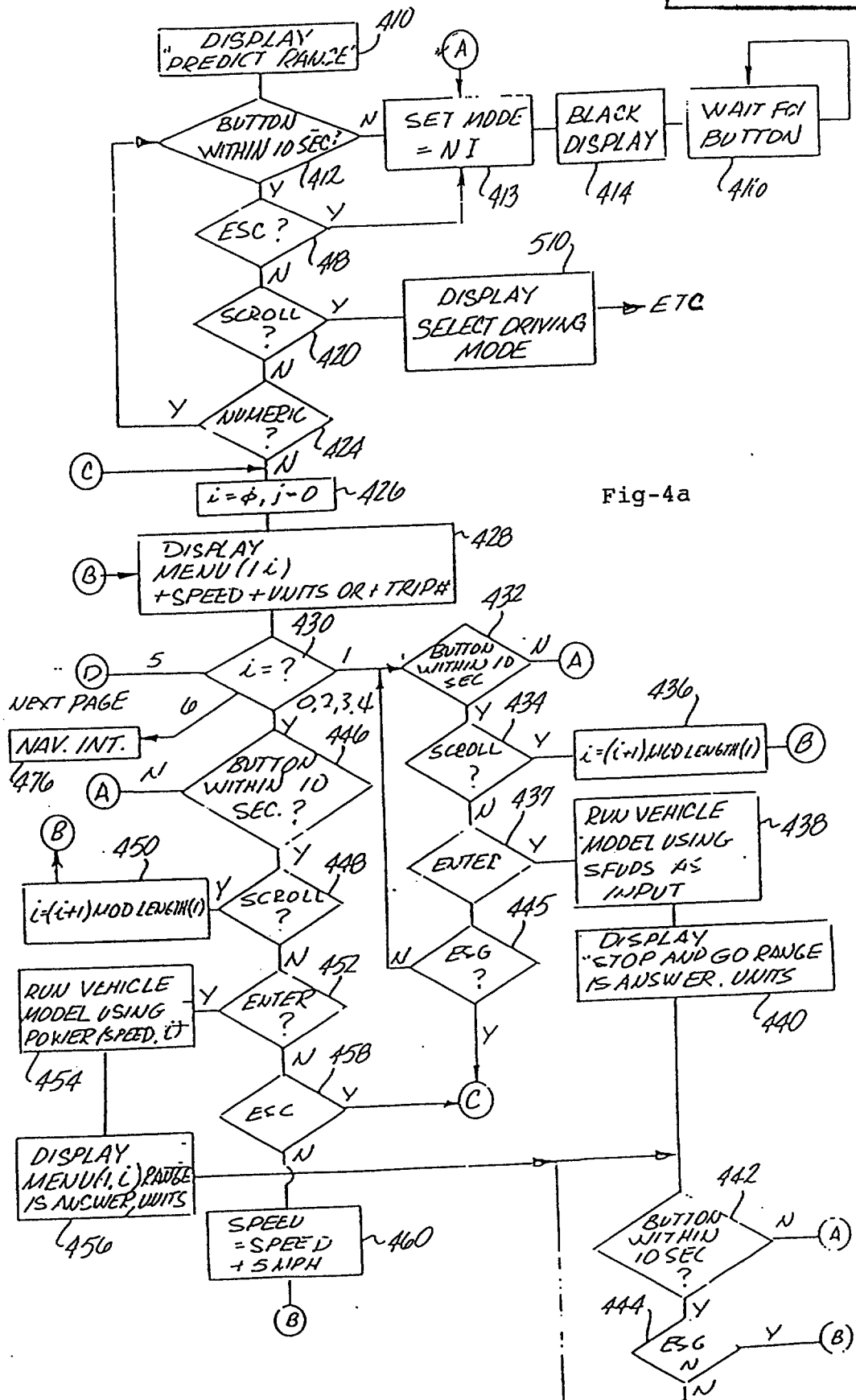


Fig-4a

Fig-4b

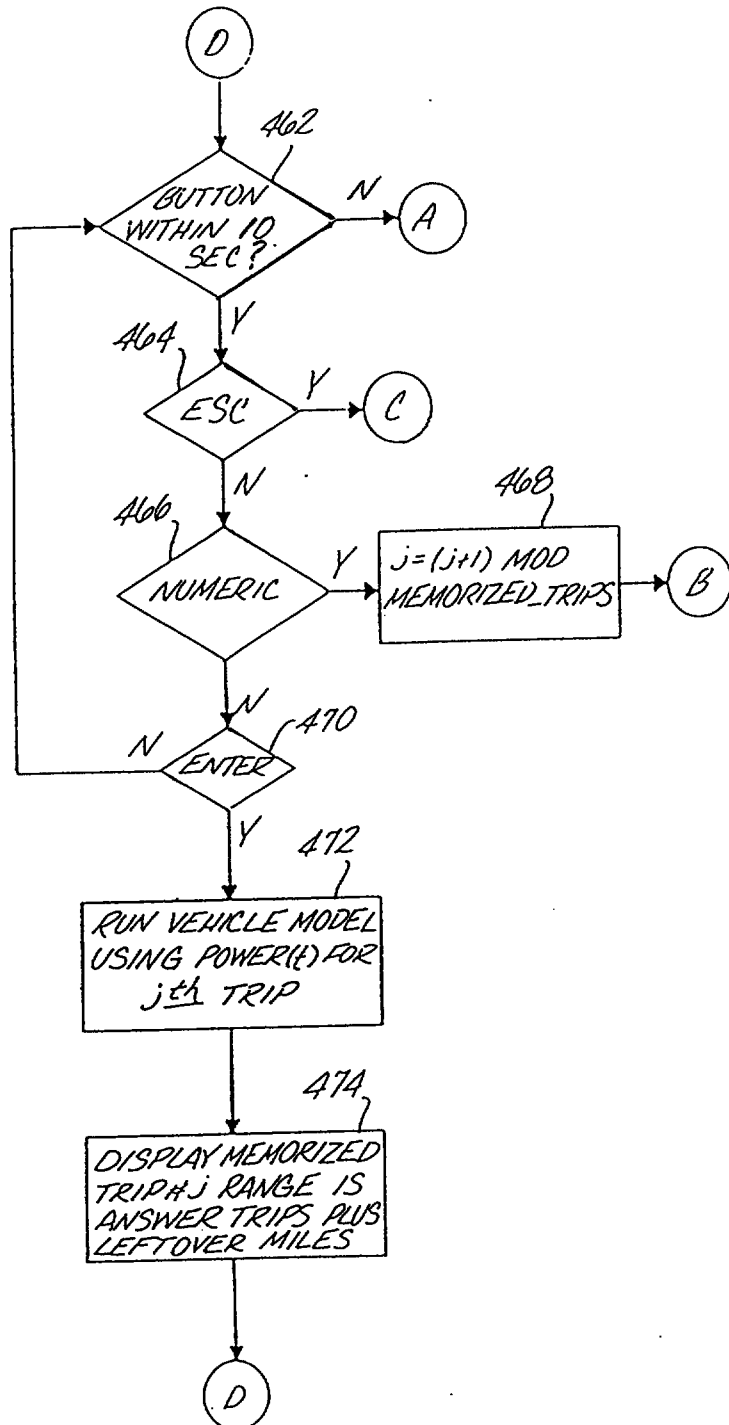


Fig-5a

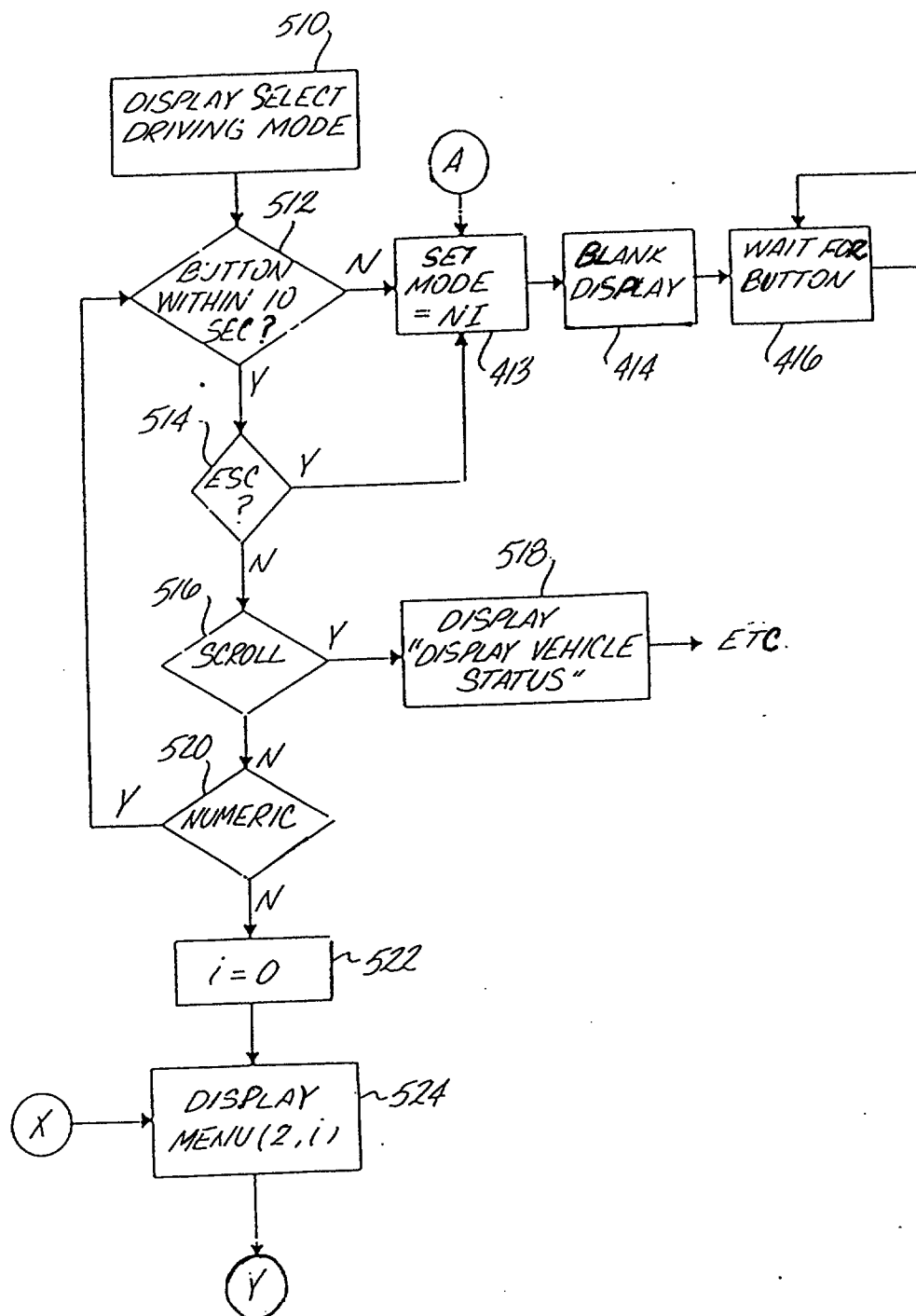


Fig-5b

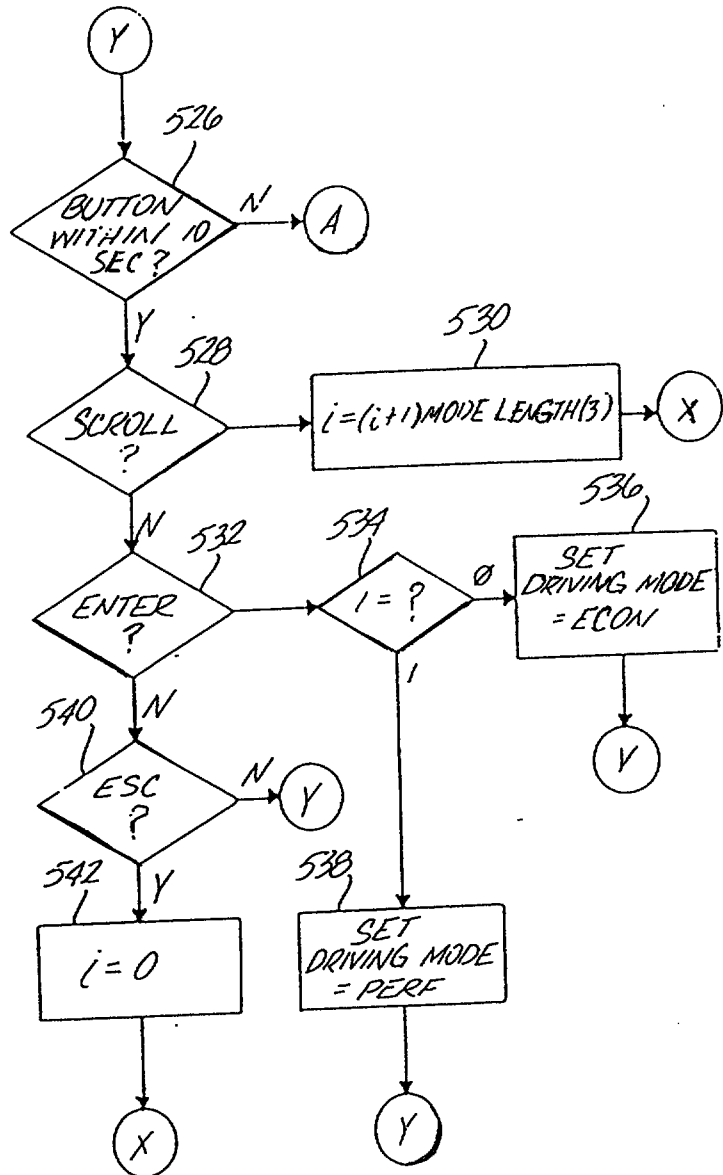
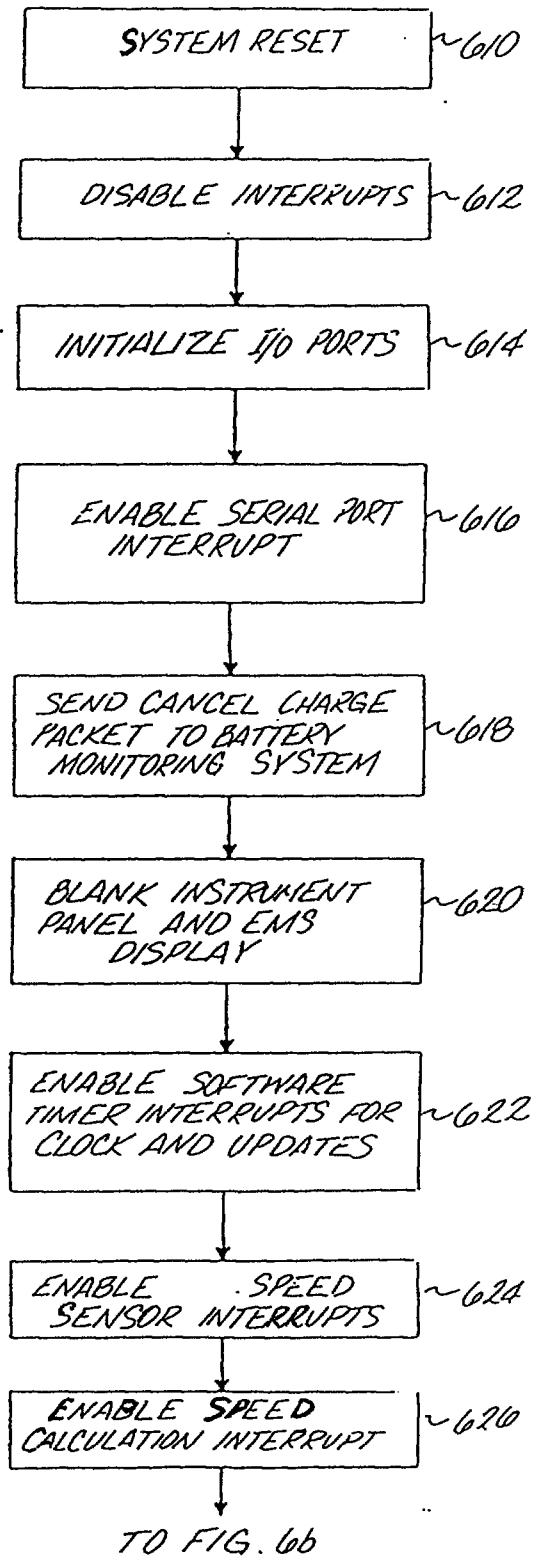


Fig-6a



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from fig-6a

Fig-6b

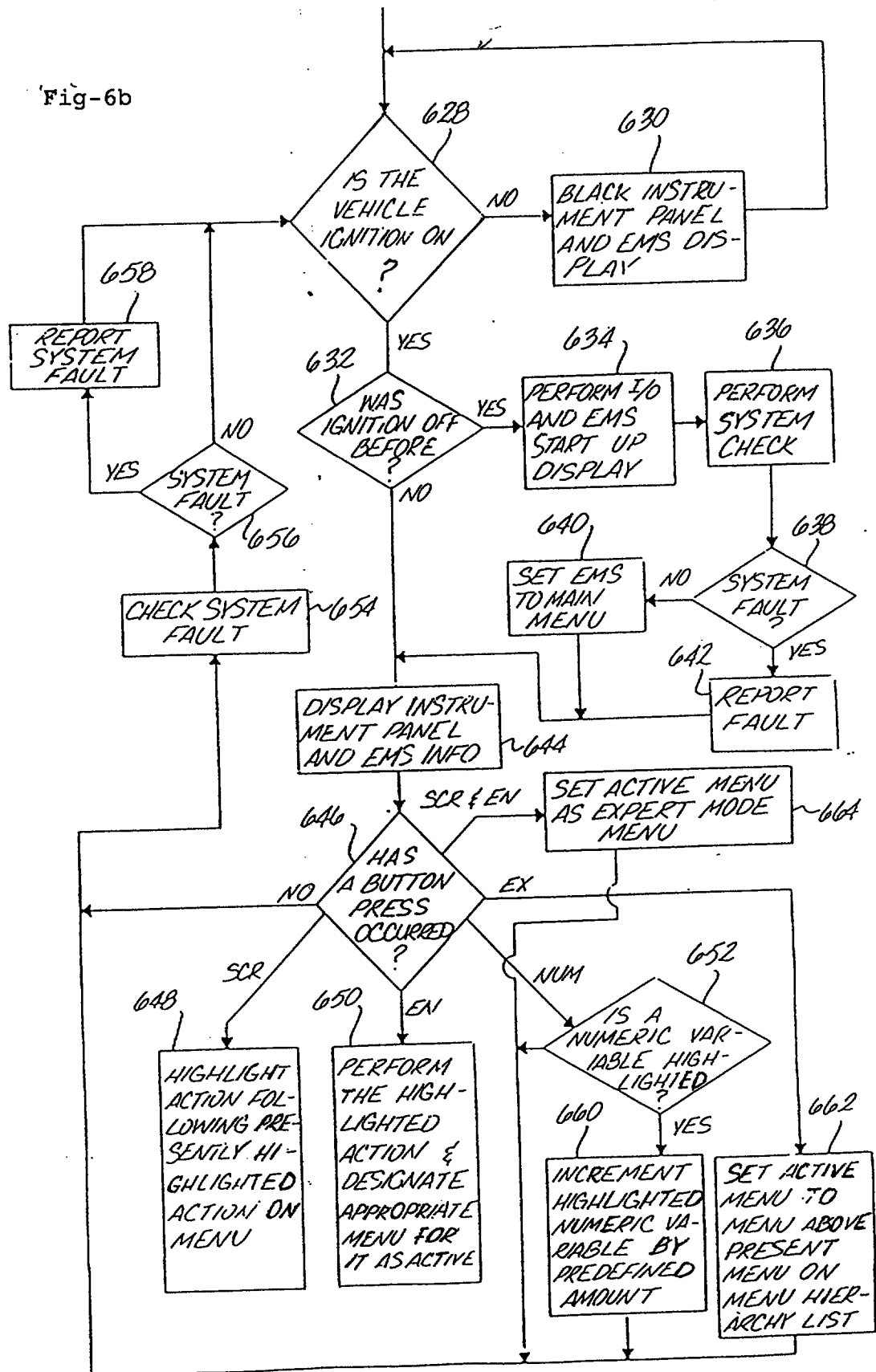
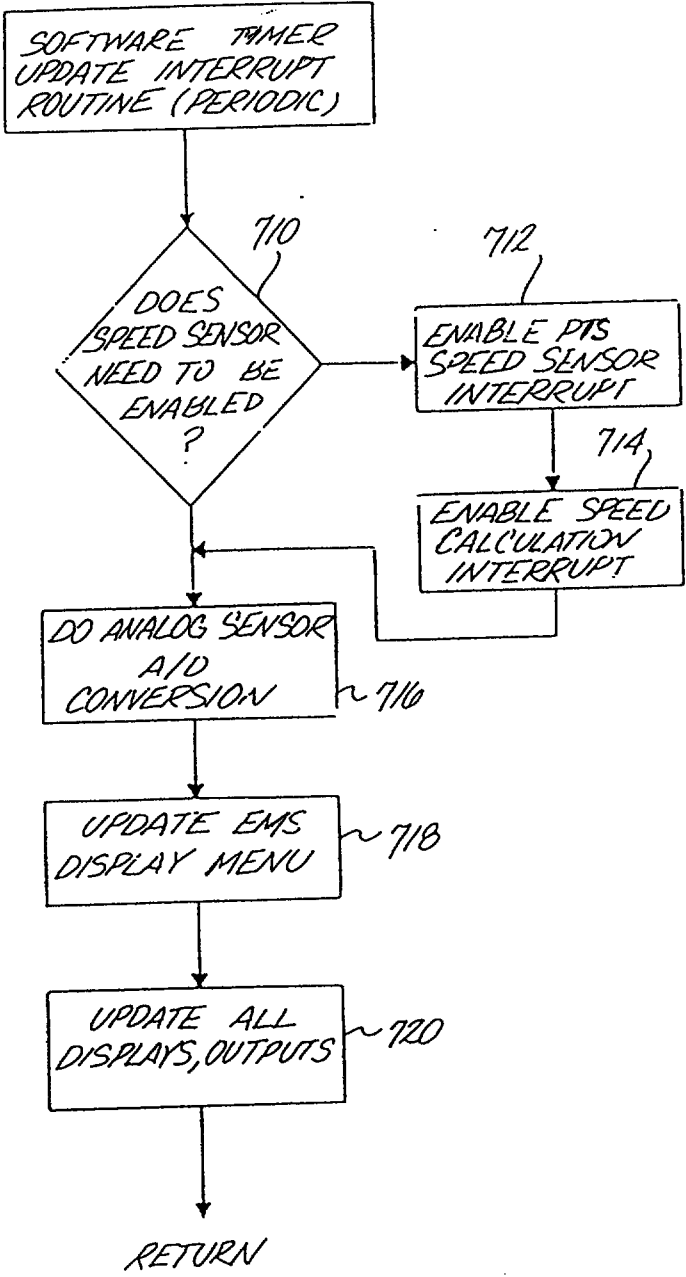


Fig-7a



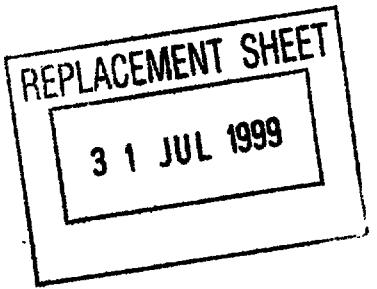
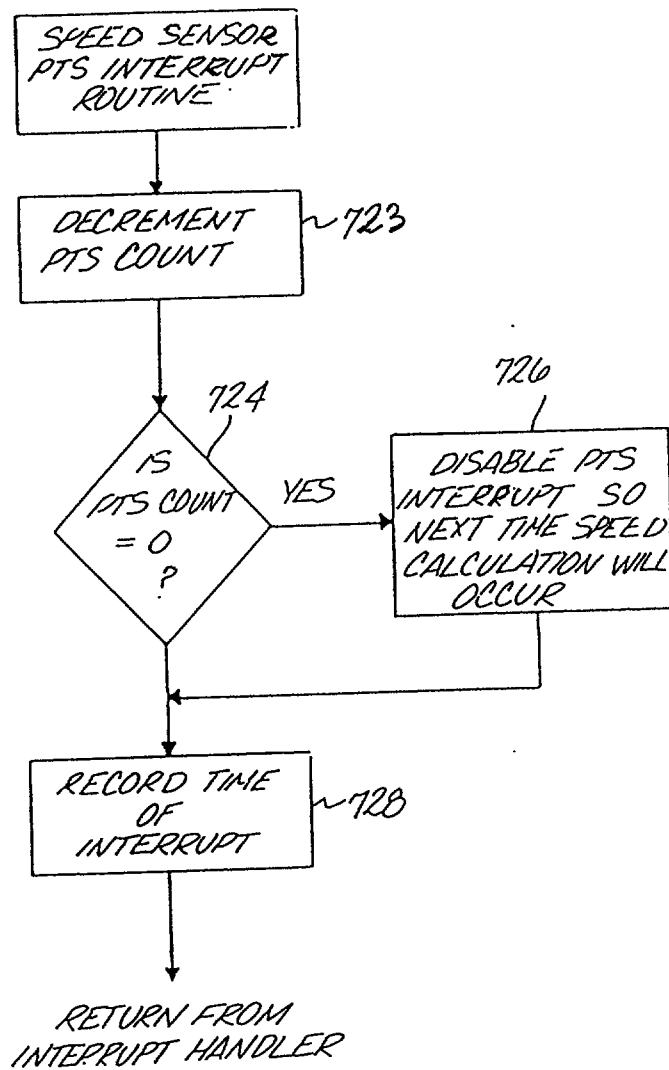


Fig-7b



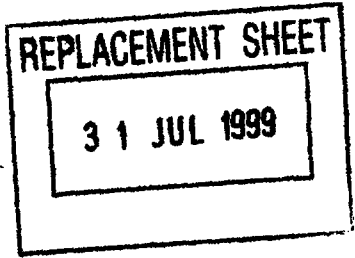


Fig-7c

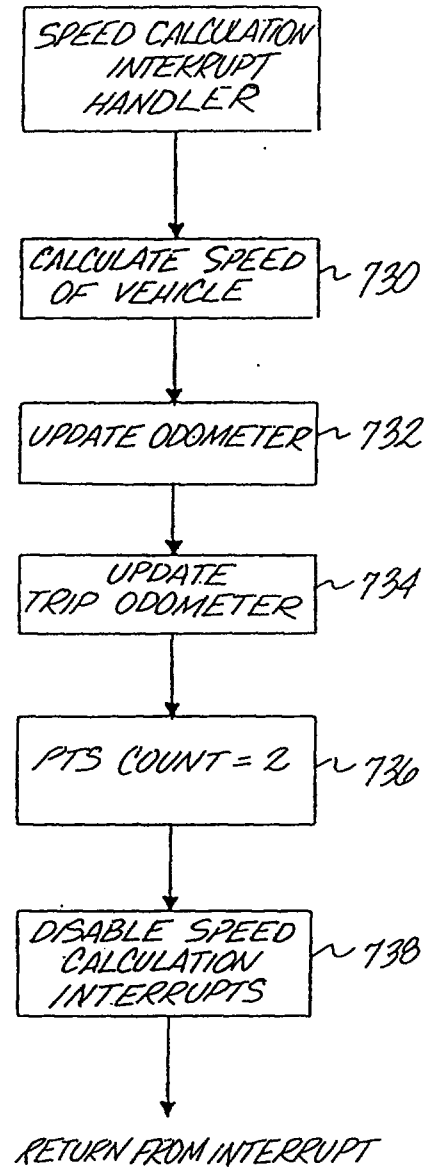
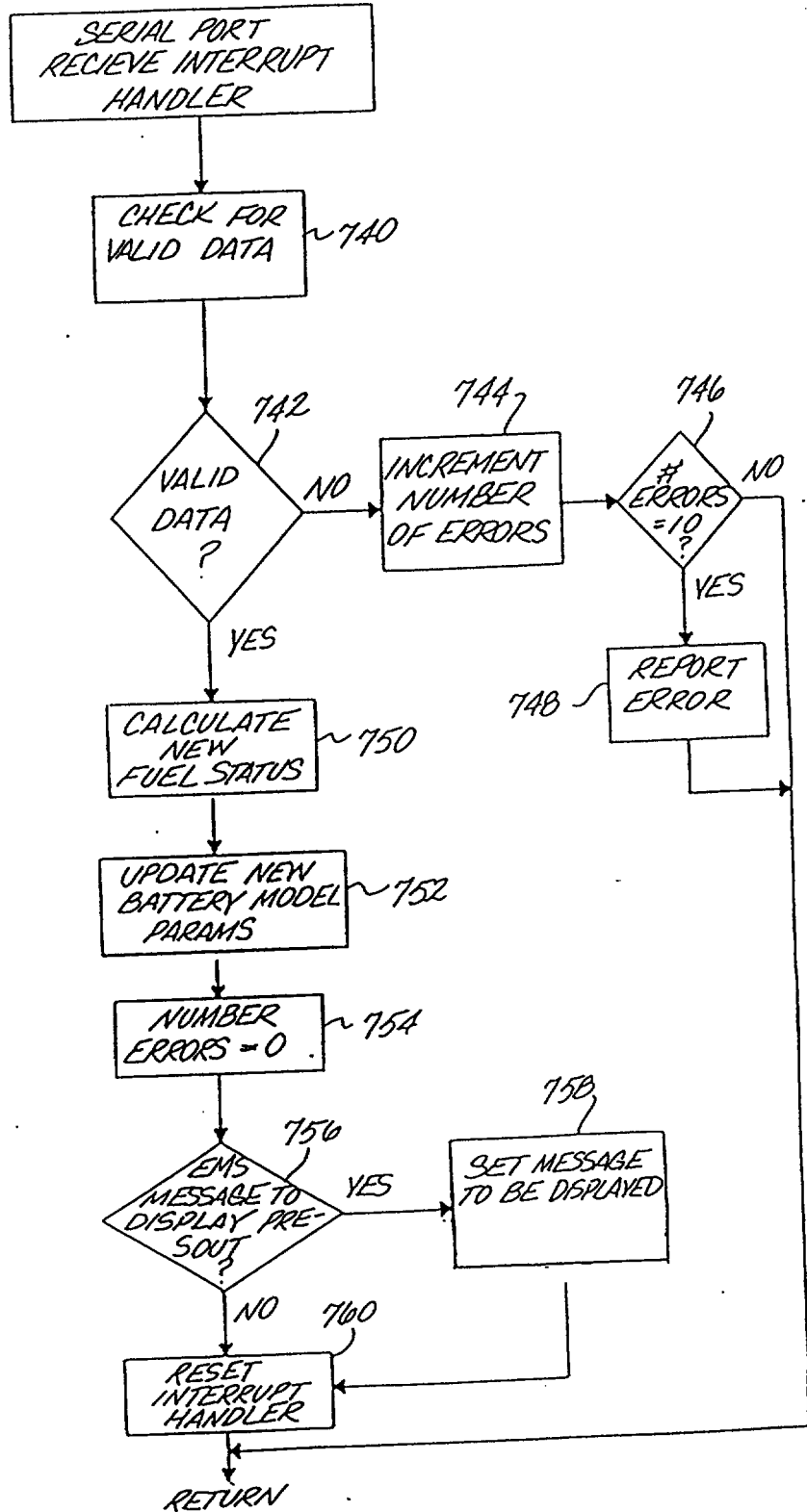
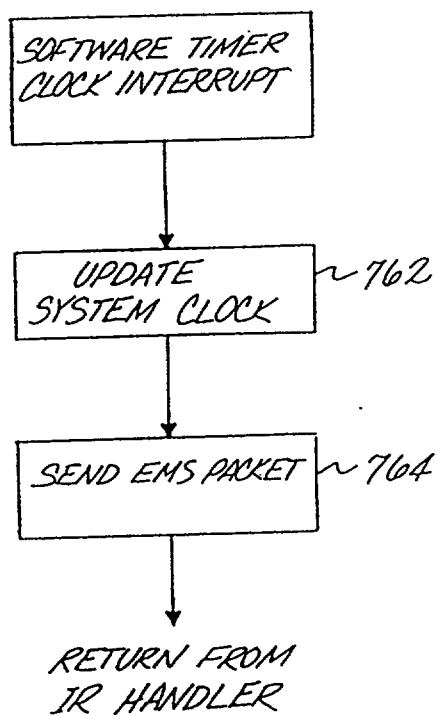


Fig-7d



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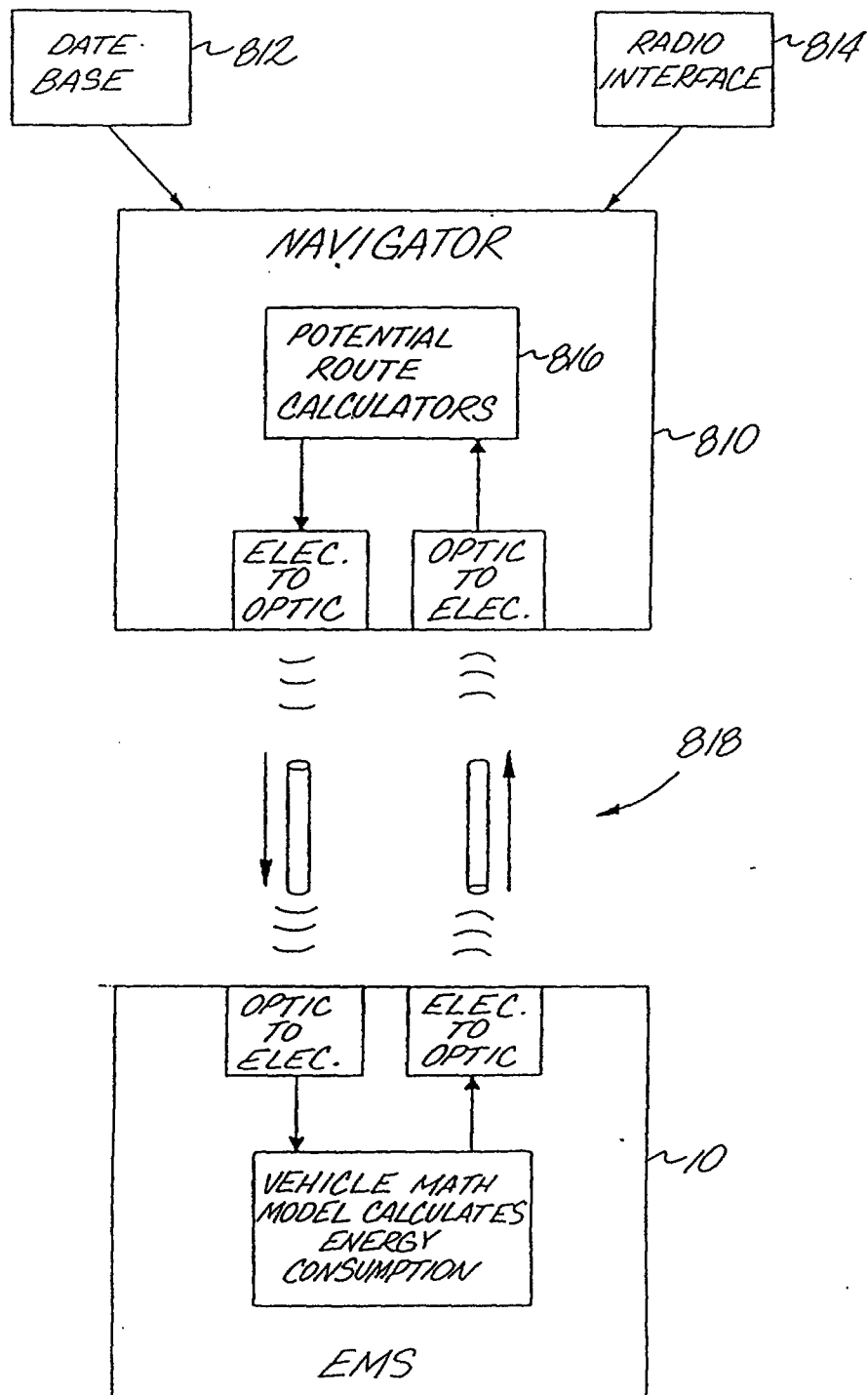
Fig-7e



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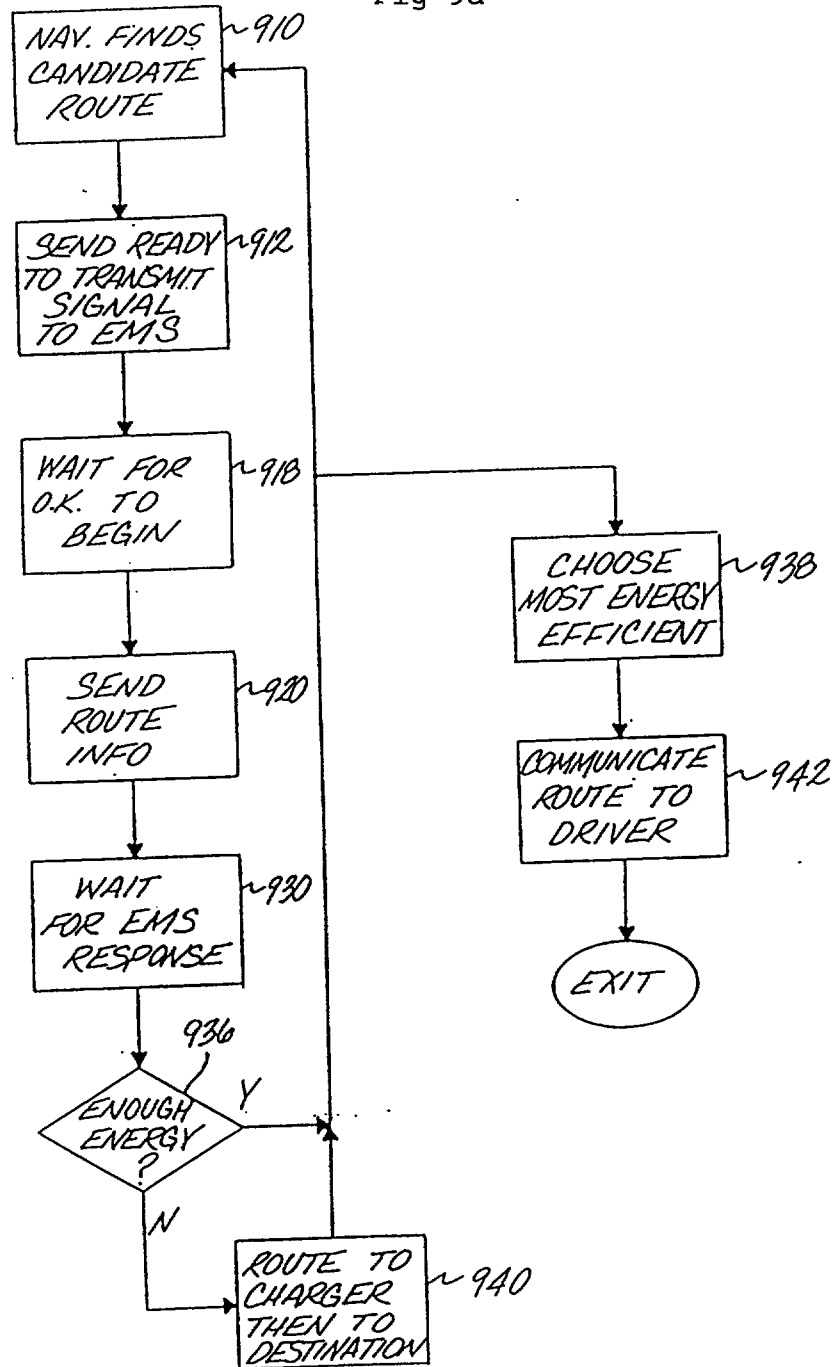
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Fig-8



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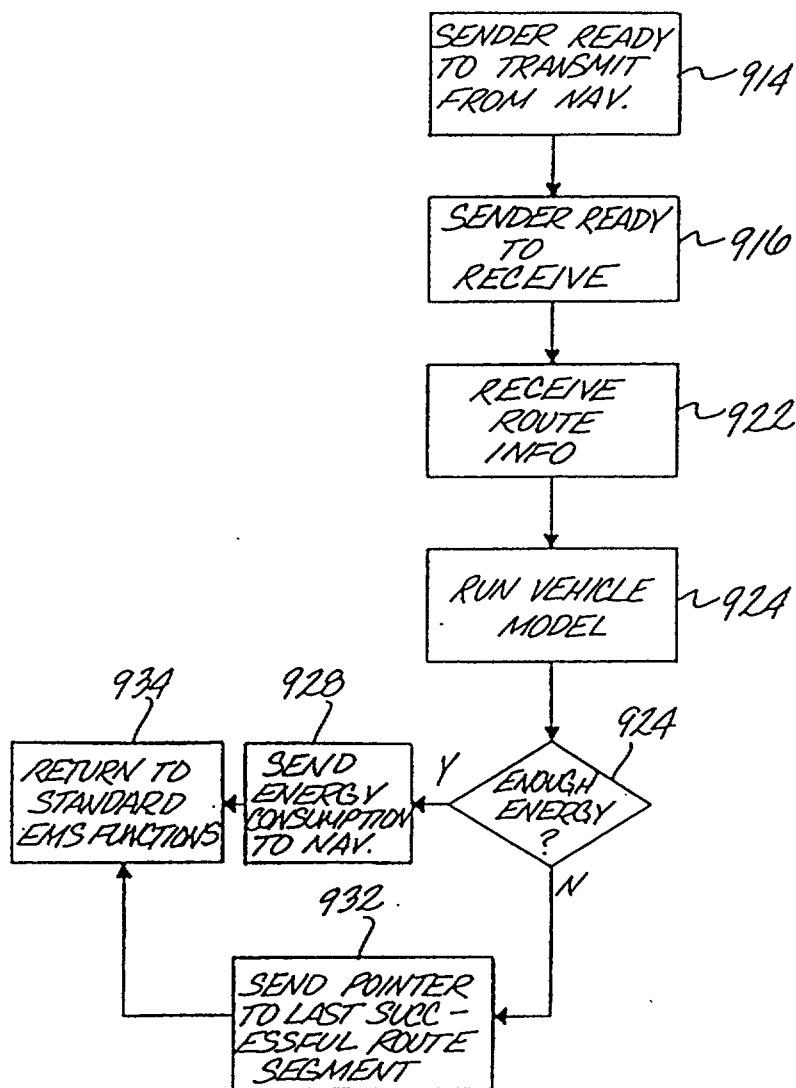
Fig-9a

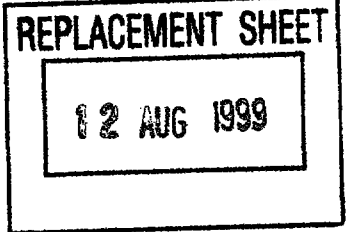


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Fig-9b





What is claimed is:

1. An energy management system, for vehicles employing a limited energy storage system, comprising:
means for receiving power status data from the energy storage system;
means for storing a plurality of predetermined driving profiles to model expected vehicle performance;
selection means for selection by the driver of one of said driving profiles;
calculation means connected to the receiving means and storage means for calculating range for the limited energy storage system based on the selected driving profile; and,
output means to display the range calculation to the driver.
2. An energy management system as defined in claim 1 wherein the driving profiles include predetermined data for standard driving cycles.
3. An energy management system as defined in claim 1 further comprising means for storing energy storage system status data from the receiving means as a function of time and wherein the driving profiles include memorized energy storage system energy consumption data from previous vehicle trips stored by the energy storage system status data storage means.
4. An energy management system as defined in claim 1 wherein the limited energy storage system comprises a battery, further comprising controllable means for charging the battery and wherein the calculation means includes means for determining a battery charging profile based on the energy storage system status data and means for controlling the battery charging means to match the charging profile.
5. An energy management system as defined in claim 1 wherein the output means comprises a menu-driven display and the selection means comprises interactive selection keys for the menu.



6. An energy management system as defined in claim 1 wherein the limited energy storage system comprises multiple storage elements with differing rates of charge and discharge, further comprising means for controllably directing regenerated energy from braking of the vehicle to a selected one of the storage elements and wherein the calculation means includes means for controlling the directing means.
7. An energy management system as defined in claim 1 further comprising:
a plurality of vehicle subsystem sensors for determining subsystem status and a second plurality of environmental sensors for receiving data on parameters effecting energy consumption by the vehicle said subsystem sensors and environmental sensors connected to the calculation means and wherein the calculation means includes means for comparing inputs from said subsystem sensors and said environmental sensors for detection of predetermined inconsistencies between at least one of said environmental sensors and at least one of said vehicle subsystem sensors indicating inefficient energy consumption by a vehicle subsystem and means for displaying on the output means a message reflecting such detected inefficient energy consumption.
8. An energy management system as defined in claim 7 further comprising control means for disabling vehicle subsystems and wherein the calculation means further comprises means for activating the control means responsive to detected energy inefficiency.
9. An energy management system for vehicles having limited energy storage comprising:
a plurality of vehicle subsystem sensors for determining subsystem status and a second plurality of environmental sensors receiving data on parameters affecting energy consumption by the vehicle;
a calculation means for comparing inputs from said subsystem sensors and said environmental sensors for detection of a predetermined inconsistency between one of said subsystem sensors and one of said environmental sensors indicating inefficient energy consumption by a vehicle subsystem;
and



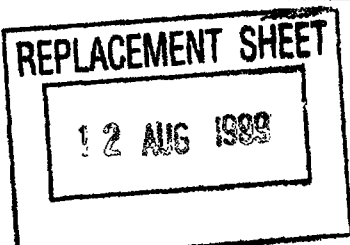
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means for providing a signal output responsive to detection of inefficient energy consumption.

10. An energy management system as defined in claim 9 wherein the signal output providing means is interactive with a driver of the vehicle and comprises a display means connected to the calculation means for display of information concerning said inefficient energy consumption and recommendations to rectify the inefficient energy consumption.
11. An energy management system as defined in claim 9 wherein the signal output providing means comprises means for directly controlling vehicle subsystems, said controlling means responsive to said calculation means.
12. An energy management system, for vehicles employing a limited energy storage system, comprises:
 - means for receiving power status data from the energy storage system;
 - means for storing a plurality of predetermined driving profiles including data supplied by a vehicle navigator for route segments between a present position and a desired destination;
 - selection means for selection by the driver of one of said driving profiles;
 - calculation means connected to the receiving means and storage means for calculating range for the limited energy storage system based on the selected driving profile; and
 - output means to display the range calculation to the driver.



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ENERGY MANAGEMENT SYSTEM FOR VEHICLES HAVING LIMITED
ENERGY STORAGE

Abstract

The Energy Management System comprises an electronic module 10 which incorporates a microcontroller 12 as a calculation engine and means for controlling various systems of an electric vehicle or other vehicle having limited energy storage. A variety of sensors including battery sensors 18, temperature sensor 20, current sensor 22, temperature sensors 24, 26, 28, 30, speed sensor 32, accelerometer 34, and ignition switch 36 provide information for the Energy Management System to derive control parameters for the systems. Automatic control of heating and air conditioning system 56, external lighting system 58 and the operation of motor controller 54 as well as display of information, status and queries to the driver are controlled by the Energy Management System and range and navigation recommendations are made based on predefined driving profiles maintained in the system.

Figure 1

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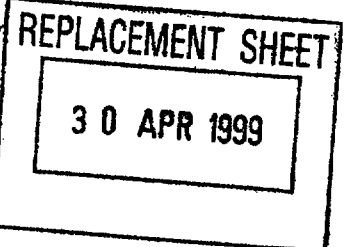


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Replacement
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What is Claimed Is:

1. An energy management system, for vehicles employing a limited energy storage system, comprising:
means for receiving power status data from the
5 energy storage system;
means for storing a plurality of driving profile data sets;
selection means for selection by the driver of one of said driving profiles;
10 - calculation means connected to the receiving means and storage means for calculating energy storage system exhaustion based on the selected driving profile; and,
output means to display the energy storage
15 system exhaustion calculation to the driver.
2. An energy management system as defined in claim 1 wherein the driving profiles include predetermined data for standard driving modes.
20
3. An energy management system as defined in claim 1 wherein the driving profiles include data supplied by a vehicle navigator for route segments between a present position and a desired destination.
25
4. An energy management system as defined in claim 1 further comprising means for storing energy storage system status data from the receiving means as a function of time and wherein the driving profiles include memorized
30 energy storage system power consumption data stored by the energy storage system data storage means.
5. An energy management system as defined in claim 1 wherein the energy storage system comprises a battery,
35 further comprising controllable means for charging the battery and wherein the calculation means includes means for determining a battery charging profile based on the



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REPLACEMENT SHEET

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energy storage system status data and means for controlling the charging means to match the charging profile.

5 6. An energy management system as defined in claim 1 wherein the output means comprises a menu-driven display and the selection means comprises interactive selection keys for the menu.

10 7. An energy management system as defined in claim 1 further comprising vehicle system status sensors receiving data on parameters effecting energy consumption by the vehicle, said sensors connected to the calculation means and wherein the calculation means includes means for
15 comparing sensor inputs for detection of inefficient energy consumption and means for displaying on the output means such identified inefficiencies.

20 8. An energy management system as defined in claim 7 further comprising control means for disengaging vehicle subsystems and wherein the calculation means further comprises means for activating the control means responsive to detected energy inefficiency.

25 9. An energy management system as defined in claim 1 wherein the energy storage system comprises multiple storage elements with differing rates of charge and discharge, further comprising means for controllably directing regenerated energy from braking of the vehicle
30 to a selected one of the storage systems and wherein the calculation means includes means for controlling the directing means.

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