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A Selection Algorithm for Power Controller Unit of Hybrid Vehicles

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Abstract—**This paper presents an adaptive power management control strategy that is based on selection algorithm for controlling gas engines and electric motor torque. The state of the art hybrid vehicle technology determines the instantaneous power split in order to increase energy efficiency. The selection algorithm, contained by the power controller unit, uses inputs of analog sensors along with commands from driver's desired speed and makes a selection of outputs from preassigned control states. These states are stored in a knowledge base for revealing engine and motor mixed control strategies. The objectives of the control strategies are to minimize fuel consumption, reduce engine-out emissions, maintain higher level safety, and keep passenger and driver's comfort as the current system.**

Keywords- Hybrid Vehicles; Intelligent Vehicles; Knowledge Base; Selection Algorithm; and Power Controller.

I. INTRODUCTION

Hybrid designs have been popular since mid 1980s. In mid year 2000, hybrid vehicles arrived in the United States, following their introduction in Japan a few years earlier. The first types of hybrids were the two-seat Honda Insight, followed by the Toyota Prius in 2001. Honda then introduced a hybrid version of its Civic sedan and Toyota offered a second-generation Prius. Ford then decided to introduce its first hybrid, which is a version of the Escape sport utility vehicle, in 2005. Now major automotive manufacturers are interested in the development of hybrid vehicles. Meanwhile, Daimler Chrysler, Ford and General Motors intend to introduce hybrid light trucks and SUV in the USA.

The structure of hybrid vehicles has two or more power sources in the drivetrain that consist of purely series, purely parallel, or series-parallel layouts [1] and are currently commercially available. These vehicles split power to allow more flexibility by interconnecting mechanical and electrical power, at some cost in complexity [2]. To balance the forces from each portion, the vehicles use a differential-style linkage connection between the engine, the motor and the head end of the transmission. The transmission is much more complex than normal gas or even electric cars. Current a hybrid power-source-management uses a simple switch mechanism, under 20 mph and runs on batteries and emits 0% emissions for higher speed and/or longer distance, it changes back to gas engine. In some cases, the gas engine is the dominant portion, and the electric motors become accessories of the gas engine. This is better than a purely electric vehicle because the electric vehicle can only travel a short distance and it requires long charging times.

The current objective of the research is to split the power instantaneously in order to increase energy efficiency. Most drivers do not enjoy being enslaved by hybrids due to its complexity. Future design of sharing powers must be synergetic, integrated, and automated. Intelligence is an important issue for implementing automation in an embedded computer with several levels of control and decisions. The selection algorithm [3] suggests designing a Power Controller Unit by using sensor data to search for strategies in the knowledge base.

Simulation software written in Java has been in use for more than 10 years in our intelligent vehicle project [4]. The software is used to simulate a driving scenario for collecting and recording a wide variety of driver performance measurements [5]. The software allows users to develop driving scenarios using objects (e.g., Sensor Data Manager, Command Mode Manager, Main Control Manager, Selection Manager, and Knowledge Base Administrator) The software also allows the configuration of different hybrid vehicle types, vehicle performance characteristics including steering, acceleration, brake and powertrain characteristics. A comprehensive help program is also provided for assistance in configuration, scenario development and other issues.

The brief outline of this paper is as follow: It starts with an introduction to describe the current research that solves a power management problem of hybrid vehicles. In section two, it covers the structure of a Power Controller Unit. In section three, there is a discussion of the design phases of the Power Controller Unit. In section four, it shows the existence of the selection algorithm and the structure of the knowledge base. In section five, it simulates the Power Controller Unit and evaluates system performance. The last section mentions the pros and cons of the selection algorithm with future works.

II. STRUCTURE OF POWER CONTROLLER UNIT

Hybrid vehicles can be categorized by the way the two power sources are mechanically coupled. If they are joined at some axis that is truly in parallel, their speed must be identical and the supplied torque must be added together. Most designs combine a large electrical generator and a motor into one unit, often located between the gas engine and the transmission, replacing both the conventional starter motor and the alternator.

When only one of the two sources is used, the other must, either rotate in an idling manner, or be connected by a one-way clutch or freewheel. To balance the forces from each portion, the vehicles use a differential-style linkage between the engine and motor connected to the head end of the transmission. Thus the torque supplied must be the same and the speed must add the exact ratio depending on the differential characteristics. When only one of the two sources is being used, the other must still supply a large part of the torque or be fitted with a reverse one-way clutch or automatic clamp.

The purpose of this paper is to explore an intelligent selection algorithm for the on-board Power Controller Unit (PCU) use. As shown in Figure 1, the PCU has options to put a sharing power path which allows more flexibility interconnecting gas engine and electrical motor. To balance the forces from each portion, there is a parallel power linkage with two power sources that can run the gas engine, or an electric motor, or a combination of both.

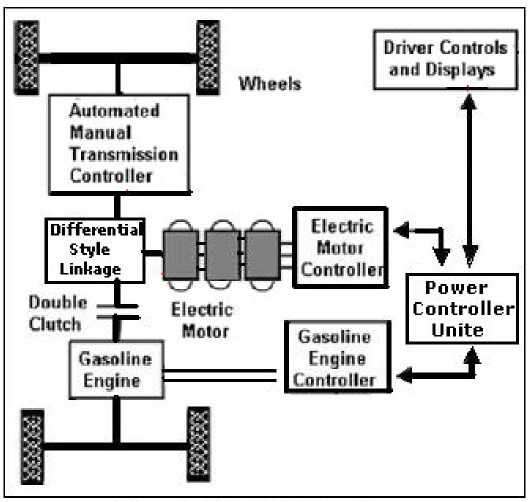

Figure 1: Hybrid Canfiguration

III. Design Of Power Controller Unit

The overall goal of the Power Controller Unit is to execute sensor data and produce control strategies. The sensor data are usually described numerically or linguistically in the domain of selection algorithm. The control strategies are used to increase safety, improve efficiency, and reduce emission impact in the output range of selection algorithm. Our approach to design the Power Controller Unit involves two phases. In the first phase, the top-down design performance specifications are established to quantify the desired behavior as the driver demands. The performance specifications are considered to be the preliminary requirements of controller design. This process imposes requirements on the controller. The second phase of the design process is bottom-up. The output range of controller is modified to take into account the objectives that we stated earlier: minimize fuel consumption, to reduce engine-out emissions, to maintain higher level of safety, and to keep passenger and driver's comfort as the current system. The implication is that, if the process is completed successfully, the hybrid vehicle system is guaranteed to satisfy the performance specifications without the need for further verification.

To conclude the bottom-up phase, the effect of the resulting hybrid controller on the physical process needs to be abstracted so that the result in emergent behavior can be evaluated. The bottom-up phase of the design process can also be thought of as a verification technique in cases where a controller has already been designed. Optimal control is used to determine the worst possible modification of the system. If the performance specifications are satisfied in this case, then they are guaranteed to be satisfied for all other modifications as well. If the performance specifications are not satisfied, the verification process reveals ways in which the design can be modified in terms of restrictions on the switching patterns of the hybrid control scheme. The modified controller is guaranteed to satisfy the performance specifications. While giving the driver full control of the car.

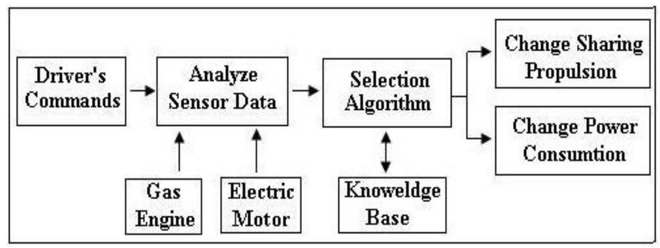

Figure 2: Controlling Process

The driver's commands are acceleration/decelerate and controlling steeling wheel as the same basic operation as usual. These hybrid vehicles have a selection algorithm that allows more efficiently ways in the drivetrain by inter-converting mechanical and electrical power. To balance the forces from each portion, the vehicles use a differential-style linkage between the engine and motor connected to the head end of the transmission. The ranges of selection algorithm are considered with different road conditions and the domains will give the optimum solution to split the powers. The software development uses pipelining, object-oriented, and a layering architecture to maximize the performance, timing, reliability and safety of the system design. The pipelining process involves the Sensor Data Manager, Main Control Manager, Selection Manager, Knowledge Base Administrator, and Command Mode Manager. The dependency and steps of the process suggest a typical pipelining architecture for the software system. The Object-Oriented Design gives the system the flexibility in future changes in the software. The Layered approach is very useful with knowledge base structures. Those structures are often arranged as a hierarchically hashing tables' lookup. As shown in Figure 2, the controlling process consists of the driver's input commands, analyzing sensor data of gas engine and electric motor, performing selection algorithm based on knowledge base, calculating sharing propulsions, and carrying out vehicle moving, and continuously changing power consumption during operation.

IV. Selection Algorithm

In our selection algorithm design, we take a wider view of what constitutes optimization. To do this, we further model the source of the inputs themselves. We assume that the total power from two different independent power sources, each of which has its own optimizations to perform, is interested in only optimizing its own operation. It is necessary to determine the instantaneous power split between two sources in order to minimize the energy consumption of the whole system.

The selection algorithm is used to determine what conditions these requirements can meet under and produce a control strategy to meet them whenever possible. The algorithm makes use of ideas from selection theory [6]. The performance is treated as integration between two sources. This process imposes further restrictions on the control strategies.

The selection algorithm is precompiled from all possible conditions in the knowledge base and its output is list in a hash table look up which computation time is counted as table search time. The computation complexity is categorized in linear time. So the designed hybrid has an expected good power, no pollution, low refueling costs, and at least 350 miles between re-fueling.

The simulator of test selection algorithm is to full charge lithium batteries and to refuel 15 gallons gasoline in fuel tank. The fuel tank and batteries will continue to be used during simulation. The operator is based upon designed scenarios of road condition and driving environment to control pedal and steering wheel.

The objectives would be to minimize fuel consumption, to reduce engine-out emissions, to maintain higher level of safety, and to keep passenger and driver's comfort as the current system. These objectives give hybrids true utilities for providing a globally optimized strategy in real time. Although many different power control algorithms were published, none of them provide to be computationally tractable (e.g., polynomial time). However, recent news from the MSR consortium (German car makers and suppliers) reports that there is no polynomial time algorithm that can implement this mechanism of mixed settings under optimal assumptions. The selection algorithm is tractable and is described as follow.

A. Theoretical Background

The description of selection algorithm is as follow: Let X and Y denote two metric spaces. Under measurable conditions of X and Y, we can assign a function Φ maps $X \rightarrow 2^Y$, where 2^Y denotes the family of non-empty subsets of Y. For every $x \varepsilon X$, there exists a selection $\Phi(x)$ which is an element of preassigned subset of Y.

The following propositions are used to guarantee the existence of selection in our knowledge base.

Definition 1. If $\{x \mid \Phi(x) \cap U \neq \emptyset\}$ is open in X for every nonempty subset U of Y, then $\Phi: X \rightarrow 2^Y$ is a lower semicontinuous function.

Proposition 1. If $\Phi : X \rightarrow 2^Y$ has the property that, for every $x_0 \varepsilon X$, there exists a selection for $\Phi|_A$ ($A \subset X$ and is a neighborhood of x_0) that has a preassigned value $y_0 \varepsilon \Phi(x_0)$, then the selection Φ is the lower semicontinuous function.

Proof of proposition 1. Let V be open in Y, We must show that $G = \{ x \mid \Phi(x) \cap V \neq \emptyset\}$ is open in X. For each $x_0 \varepsilon G$, pick a $y_0 \varepsilon \Phi(x_0)$. Then by assumption, there exists a selection f for $\Phi|_A$, for some neighborhood A of such that $f(x_0) = y_0$. Now if $U = A \cap \{x \mid f(x) \varepsilon V\}$, then U is a neighborhood of x_0 that is contained in G. Hence G is open and the proof is complete.

Proposition 2. If X, Y are metric space then every lower semicontinuous function Φ from X to the nonempty closed subsets of Y has a selection.

Proof of proposition 2. To prove this, it is sufficient if we construct a sequence of continuous functions f_n: $X \rightarrow Y$ such that for every $x \varepsilon X$. Let $\{ f_n \}$ be uniformly Cauchy and hence converge uniformly to a continuous f and that it follows $f(x) \varepsilon \Phi(x)$, for every $x \varepsilon X$. Let $\Phi_{n+1} (x) = \Phi(x) \cap f_n (x)$. Then $\Phi_{n+1}(x)$ is never empty by induction hypothesis. That implies Φ_{n+1} is the lower semicontinuous. Hence $\Phi_{n+1} \rightarrow \Phi$ has a selection. This completes the proof of proposition 2.

B. Knowledge Base Structure

The knowledge base provides a long-term storage for the control strategy selection. The storage stream implements an item of knowledge base. The strategies in the knowledge base are addressed by the unique control-ID returned to the function call on Retrieved( ) operation. The database is implemented with three objects: Database, Structure and Stream. Knowledge base is the super class which is used by all control objects. Structure and Stream are subclasses that provide interface to the hardware and are used only by control object.

Classification and categorization of knowledge database is an important part of a successful selection implementation. The domain (i. e., set X) of the selection algorithm consists of sensor data of gas engine and electric motor. The elements of X are Fuel System Status, Optimize System Status, Engine Load Value, Engine Coolant Temperature, Fuel Pressure, Intake Manifold Absolute Pressure, Engine RPM, Vehicle Speed, Timing Advance, Throttle Position, MAF air flow rate, Oxygen Sensor Voltage, Run time since engine start, etc.

As shown in Figure 3, the gas engine (E) divides the power percentage from 0% to 100% of maximum power into eleven states; similarly electric motor (M) has eleven states. Where 0% is the state of idling state and 100% is full speed state. The Cartesian product of 11 by 11 is equal to 121 states which are the range (i. e., set Y) of the selection algorithm. Each state has the control commands of power contribution details.

V. SIMULATION AND EVALUATION

The selection algorithm's control strategy is simulated on a typical driving scenario. The results of simulation significantly reduce the analysis time and complexity of different vehicle road test procedures. They help understand the impact of the improvement the selection algorithm has on the testing values of the whole vehicle system. The evaluation supports the designer of control strategies as well as overall Power Controller Unit of hybrid vehicles.

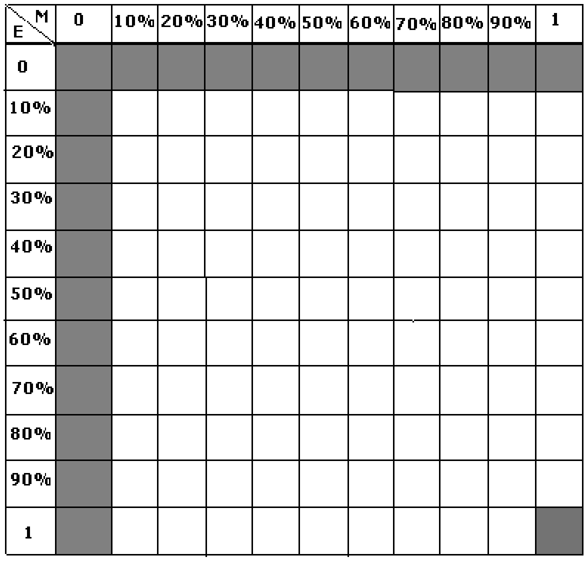

Figure 3: Tracability Matrix

VI. SIMULATION AND EVALUATION

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The simulation is to show feasibility of the system by exploring selection algorithm. As shown in Figure 4, the software components consist of Sensor Data Manager, that collect data with on-board sensors, and a Selection Manager that is concerned with high level management of the sensor data and interpretation of data. The sensors include altimeter, barometer, thermometer, wind speed measurer, etc. The data of the commands that are input from the driver are transferred through a data bus link. The low-level management, such as obstacle avoidance, is performed locally with the help of a built-in knowledge base. This document describes only the probe systems. The Main control manager as well as the simulation software consists of the following objects.

- Sensor Data Manager – drivers for the array of sensors data.
- Command Mode Manager– drivers for driver's speed control data.
- Main Control Manager – Power Controller Unit component has responsible for managing other subsystems, as well as controlling hybrid systems.
- Selection Manager– selection algorithm for searching sharing powers between motor and engine torques.
- Knowledge Base Administrator– a subsystem.

Command Mode Manager initiates the flow of command to the Main Control Manager which forwards to Sensor Data Manager for receiving Sensor Data and Command. Command Control Manager routes received-data and commands to Selection Manager for analyzing and processing. Selection Manager also sends analyzed data to Knowledge Base Administrator for selection algorithm to search optimal strategies.

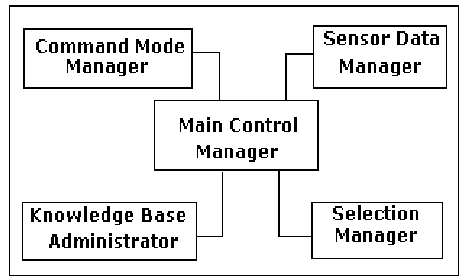

Figure 4: Simulation Objects

Some simulation results are present in Figure 5. In this simulation, the response of the hybrid system to given input signal profiles is being observed. The input to hybrid vehicle engine and motor is the mixed command which is directly related to the accelerator pedal Driver's command speed and the torque absorbed by the transmission. The profiles of the index and the load torque have been selected to demonstrate the reaction of the system states to different input changes.

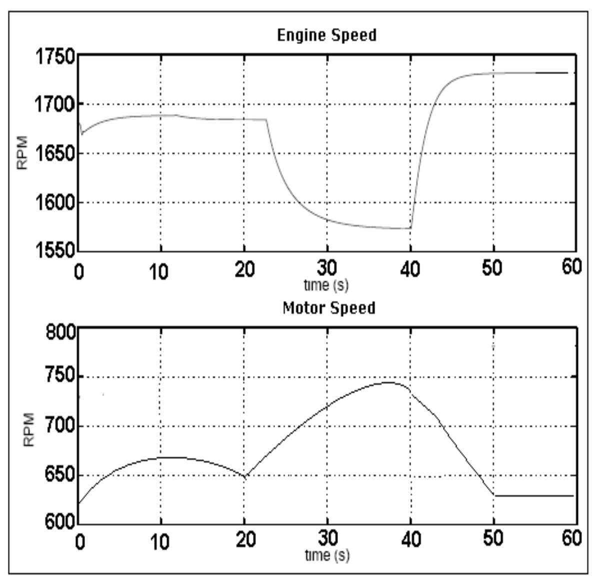

Figure 5: Simulation Results-1

First, at t = 23s, engine input signal is decreased simultaneously, leaving the motor speed increased. The decrease of the indicated torque due to the decreased fuel mass is compensated by motor support for the higher load torque. As a result, the net torque is stable and thus the combined speed remains constant. At t = 40s, the motor speed is decreased, which caused engine speed to increase then the combined speed to remain in a stable condition.

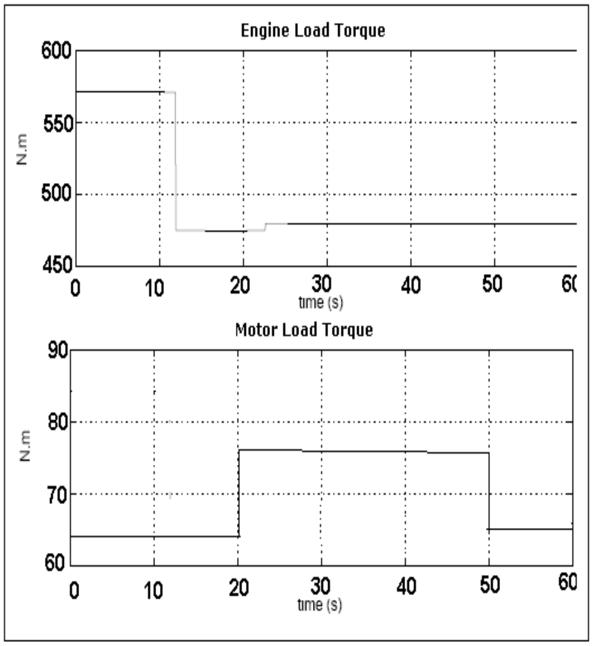

Figure 5: Simulation Results -2

Since we have not used road testing data, we built our simulation model based on empirical data available in our knowledge base. These results are obtained for supporting design validity. The response of the engine speed and the motor speed to changes in the fuelling rate and electric current as well as load torque are expected. Most of the other variables in the design are input by driver's command accordingly. The performance of the selection algorithm is based upon the Root Mean Squared Error (RMSE) of 15rpm.

VII. CONCLUSIONS

The advantage of the selection algorithm is to operate under timing constraints and handle unpredictable conditions. The timing constraints are most critical for the power Controller Unit. The unit has an internal memory buffer that is filled up with sensor data in time. At the hardware level, the design uses 32-bits data bus that allows fast direct-memory-access controller (DMA) of the knowledge base storage. Also, one microprocessor is dedicated to handle the computation that must be completed before withdrawing the next round of sensor data. Another microprocessor handles other computations that are not crucial to the next round of data. For unpredictable conditions, the intelligent selection algorithm will pick a best strategy of the knowledge base, so that the unit can adjust vehicle speed to the changing environment.

The disadvantage of such a layout is that the pre-computed values are only optimal for a certain type engine and motor. As the hybrid vehicle model changes, the system will have to reset its knowledge base and computer system.

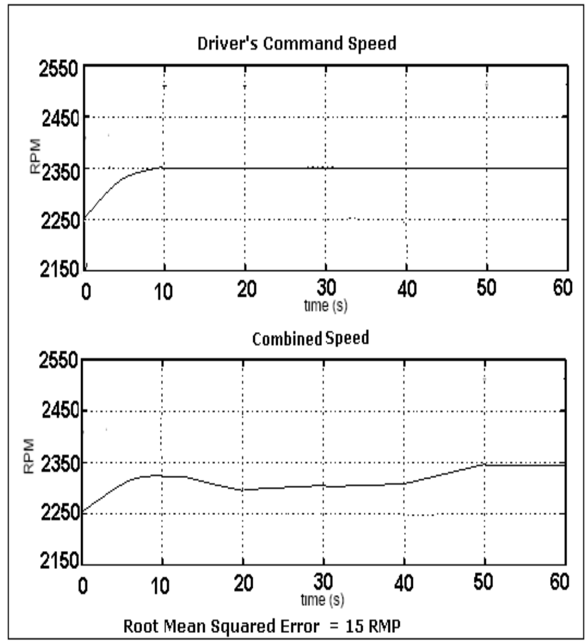

Figure 5: Simulation Results -3

The future work of this Power Controller Unit is that it should have a self diagnostic mode. It can detect a problem early on and warn the driver with an indicator light on the dash. A technician can then plug test equipment in and retrieve a list of troubled codes that will help pinpoint where the problem is. Also, the system can learn from results of certain operations, and handle certain device failures, because the strategies are in the knowledge base.

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