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Energy Optimization and Transfer in Electric Vehicles via Mechanical Coupling

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ABSTRACT

Electric vehicles have a limited range due to limited battery capacity. Also, such vehicles, while having a lower carbon footprint than gasoline vehicles, do not address capacity issues on the road network. The relative sparsity of charging stations and the length of time needed to achieve a full charge can be a hindrance to some EV drivers. This disclosure describes an automatic coupling mechanism between electric vehicles that enables energy transfer between coupled vehicles. Based on commonality of routes, determined with user permission, vehicles automatically form mechanically coupled trains. Vehicles within a train with high energy drive the train and optionally, transfer energy to vehicles with low energy. The price of energy transfer can be determined by an automatic, real-time auction agreed to by the various drivers. Vehicles behind the first one in the train enjoy reduced drag and greater efficiency by slipstreaming behind their predecessors in the train.

KEYWORDS

- Vehicle-to-vehicle (V2V) communication
- Railroad car coupling
- Autonomous driving
- Self-driving
- Semi-autonomous driving
- Regenerative braking
- Drafting effect
- Slipstreaming
- On-the-fly refueling
- Energy tanker
- Drag reduction

BACKGROUND

While electric vehicles (EVs) have a lower carbon footprint than gasoline vehicles, they don’t address capacity issues on the road network. Traffic congestion remains an important problem in many parts of the world. Also, EVs have limited range due to limited battery capacity. The relative sparsity of charging stations and the length of time needed to achieve a full charge can be a hindrance.

DESCRIPTION

This disclosure describes an automatic coupling mechanism between electric vehicles that enables energy transfer between the coupled vehicles. Based on commonality of routes, vehicles automatically form mechanically coupled trains. Vehicles within a train with high stored energy drive the train and optionally, transfer energy to vehicles with low stored energy at prices agreed upon by vehicle owners. For example, the price of energy transfer can be determined by an automatic, real-time auction.

Vehicles behind the first one in the train enjoy reduced drag and greater energy efficiency due to slipstreaming behind their predecessors in the train. Long haul drivers who don’t wish to stop to recharge their vehicles can achieve vehicle recharging on-the-fly from short distance drivers who don’t mind recharging frequently. The techniques enable an energy-tanker business whose service objective is to join trains of vehicles to recharge them in motion, thereby alleviating the difficulties that arise from the relative sparsity of charging stations. Grouping together of vehicles by commonality in routes can reduce congestion and can help optimize road capacity.

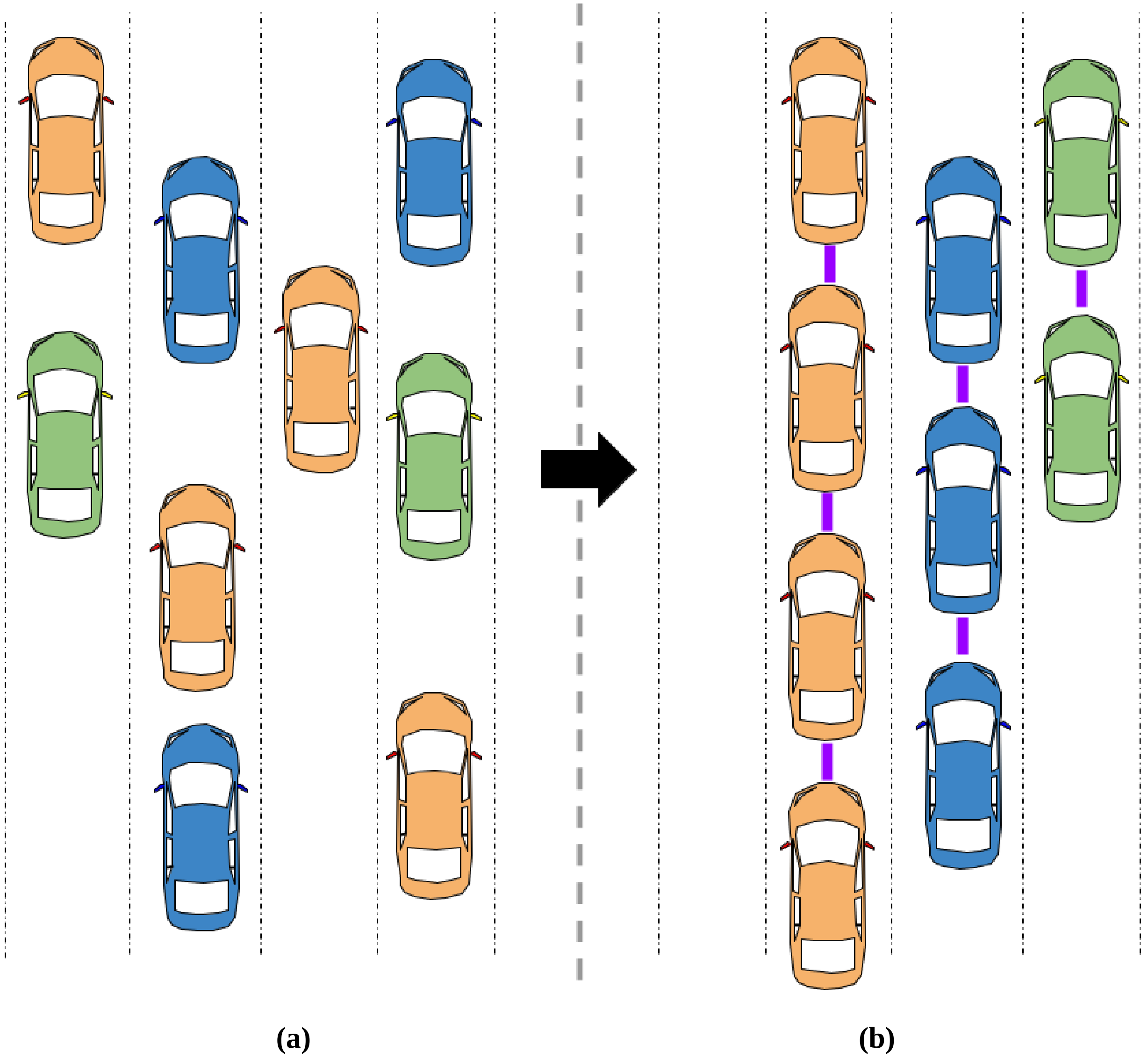

Fig. 1: Energy optimization and transfer in electric vehicles via mechanical coupling. Vehicles of like color have a substantial overlap in route. (a) In conventional highway occupancy, vehicles do not cooperate and occupy random relative locations on the highway. (b) Using V2V communications, vehicles determine peers with substantial overlap and group themselves into trains, enabling more efficient usage of highway space, better fuel efficiency, on-the-fly energy exchange between vehicles in a train, load balancing, etc.

Fig. 1 illustrates an example of energy optimization and transfer in electric vehicles via mechanical coupling. In this example, vehicles of like color have a substantial overlap in route. In conventional highway occupancy (Fig. 1a), the vehicles do not cooperate and occupy random relative locations on the highway. In contrast, per the techniques of this disclosure, with permission from appropriate occupants in each vehicle, the vehicles use V2V communications to identify peers with substantial overlap and self-organize into trains (Fig. 1b), enabling more efficient usage of highway space, better fuel efficiency, on-the-fly energy exchange between vehicles in a train, load balancing, etc.

Vehicle owners/occupants can choose to participate in such an arrangement and can choose to only reveal a limited amount of information to permit such computation. For example, a vehicle may only reveal that its current route includes “at least 200 miles further on this highway” or “heading towards City X” rather than a detailed route. In another example, the vehicle owner can only reveal “able to provide up to X kWh charge to other vehicles” or “need Y kWh of charge” rather than revealing own battery level. Vehicle owners can select appropriate settings for such information sharing or can manually respond to requests. If the vehicle owner chooses to not participate, no information is shared and the vehicle can operate in independent mode, per current norms.

Mechanical coupling between vehicles can be achieved using coupling devices in vehicle bumpers, similar to coupling devices that link rail cars. Any two vehicles equipped with such devices can link up mechanically, forming a train with a somewhat flexible joint able to transmit both acceleration and braking force. Together with autonomous navigation and vehicle-to-vehicle (V2V) communication, vehicles can be coupled and decoupled on-the-fly, e.g., while they are in motion on a highway. The smooth bringing together of cooperating vehicles, e.g., at near-zero relative velocities can be achieved using autonomous driving and V2V communication.

A train of vehicles can be quite long, e.g., several vehicles, possibly limited at some point by traffic issues. For example, the maximum length of the train may be restricted to enable overtaking of the train by another vehicle, to avoid obstructing on/off-ramps, etc. Since vehicles can couple and decouple autonomously at any time, any member of the train can join or disconnect at will; even if a vehicle departs from the middle, the train can simply reconnect after such a departure.

Linking and unlinking is locally coordinated using local area V2V communications to find other vehicles with route overlap. The link-unlink functionality can advantageously be integrated with the onboard mapping/navigation software. Operators of fleet vehicles can coordinate over a wider area and with greater control; e.g., planning for a group of delivery trucks to drive the same route together using multi-route planning software.

Some advantages of on-the-fly coupling of electric vehicles as described herein include:

- *Safety*: Coupled vehicles effectively touch each other and maintain zero relative velocity, even at substantial highway speeds. The chances of collision between them are thereby reduced.
- *Highway capacity*: The grouping together of vehicles by commonality in routes reduces congestion and optimizes road capacity.
- *Fuel efficiency*: Vehicles behind the first one in the train enjoy reduced drag and greater energy efficiency due to slipstreaming (also known as drafting) behind their predecessors.
- *Load-balancing*: All the vehicles of a train being powered, there is an opportunity to balance loads across the vehicles based on a variety of criteria. For example, if vehicle A has a nearly full battery and the battery of vehicle B is nearly empty, vehicle B can disengage its motor and have vehicle A drive the train. More generally, load can be optimized based on battery state, distance remaining on the common route, vehicle owners’ discretion, etc.

- *On-the-fly energy marketplace*: Consider a case where vehicle-A is taking a 400-mile trip and vehicle-B is taking a 100-mile trip that happens to overlap. Using vehicle-B to supply energy during the overlapping segment can save enough of vehicle-A battery to enable vehicle-A to avoid a recharging stop, effectively increasing its range. In exchange for this service, the owner of vehicle-A can pay the owner of vehicle-B at a rate that enables the vehicle-B owner to replace the lost energy (by recharging offline later) at a profit.

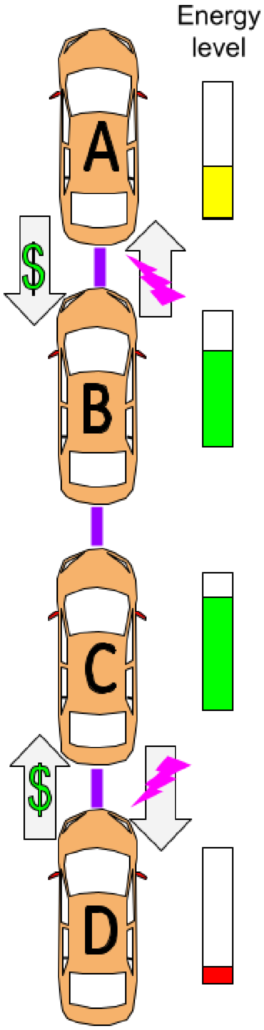

Fig. 2: Illustrating an inter-vehicle energy marketplace

In this manner, as illustrated in Fig. 2, a dynamic inter-vehicle energy market can emerge, where drivers with an energy deficit can pay to receive energy from drivers with excess energy. In example of Fig. 2, vehicle A, with an energy deficit, pays vehicle B, with an energy surplus, to recharge its battery while in motion. Vehicle D, with an energy deficit, pays vehicle C, with an energy surplus, to recharge its battery while in motion. Additionally, vehicles B and C, with ample energy reserves, can act as locomotives to drive the train, while vehicles A and D, with lower energy reserves, can be pulled along passively.

A vehicle can have excess energy if it is traveling a short distance and can recharge later from a stationary charger. A vehicle can have an energy deficit if it is traveling a long distance and its driver is unwilling to stop to recharge or its route has a dearth of charging stations.

Prices in the on-the-fly energy market can be negotiated via a local auction run over the V2V communication network. Fleet vehicle operators can optimize across their own vehicles using metrics suitable for their business.

Energy-tanker vehicles:

The above-described energy marketplace enables energy-tanker vehicles, whose service objective is to meet up with energy-demanding vehicles in motion, sell them energy as they travel, and then return to a charging point to recharge. This service may be useful to people in a rush who don’t want to stop to recharge; to fleet vehicles (e.g., inter-city delivery vehicles on a tight schedule); for getting short-range vehicles through areas that lack charging infrastructure or desirable stopping points; etc.

Rapid energy transfer: For routes that lack sufficient overlap, it may be possible to increase the energy transfer rate, e.g., via a high-capacity connector in the coupling device or via regenerative braking. Energy transfer via regenerative braking can be achieved as follows. Energy is to be transferred from vehicle A to vehicle B while they are attached. Vehicle B engages its regenerative brakes while A provides extra acceleration to compensate. In contrast to traditional braking, which transforms a loss in kinetic energy to heat (and thus wastes energy), regenerative braking transforms a loss in kinetic energy to an increase in electrically stored energy. Vehicles A and B continue to travel at highway speeds even as the (mechanical) energy of vehicle A is transferred relatively quickly to the (electrical) energy of vehicle B.

CONCLUSION

This disclosure describes an automatic coupling mechanism between electric vehicles that enables energy transfer between coupled vehicles. Based on commonality of routes, determined with user permission, vehicles automatically form mechanically coupled trains. Vehicles within a train with high energy drive the train and optionally, transfer energy to vehicles with low energy. The price of energy transfer can be determined by an automatic, real-time auction agreed to by the various drivers. Vehicles behind the first one in the train enjoy reduced drag and greater efficiency by slipstreaming behind their predecessors in the train.

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