Architecture of a Generic Vehicle Controller

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Abstract

This article treats the concept of a generic vehicle controller. This concept is succesfully applied providing both manual control and fully automatic guidance of more than ten completely different vehicles. They differ in their physical wheel configuration, steering and driving equipment, and the interfacing of sensors and actuators. Focus of this paper is the architecture of such a generic vehicle controller combining the strength of generic algorithms and the flexibility needed to add new equipment.

1 Introduction

A lot of research is done on automatic guided vehicles. This is usually restricted to a specific vehicle model (e.g. a differentially driven vehicle, having additional passive castor wheels for support). In addition, simplifications are made in order to focus on certain control or estimation aspects (e.g. neglecting the steering geometry: track rods, fusee distance, etc.).

The advantage of this approach is the short path to realisation of a guided vehicle. A few simple equations are sufficient to model the kinematics (usually neglecting dynamics) of a vehicle. Unfortunately, the results are only applicable to the chosen vehicle model.

Being employed by a company selling control systems for automatic guided vehicles [1], we are faced to the reality that vehicles appear to be very different in structure, equipment and interfaces to sensors and actuators. In our view, it is not cost effective to realise dedicated products for all these different vehicle models. In the contrary, we should minimise the effort to realise a solution for a specific vehicle.

The next section tries to capture the fundamentals for guided vehicles in general. They are the preassumptions for a section about the architecture for a generic vehicle controller. The architecture is a framework in which a fixed set of control and estimation algorithms were developed to be used for all common vehicle models. They appeared to be applicable to more then ten completely different vehicles (example see figure 1).

Fig. 1. Example of a complex vehicle having many degrees-of-freedom. The Phileas [2], an articulated vehicle for public transportation, planned to be in service next year (Eindhoven, The Netherlands)

2 Fundamentals

In general, most vehicles have a few fundamental features in common. This is especially the case regarding vehicles performing a meaningful transportation function of people or goods.

A guided vehicle is a mobile platform that should carry a load along a path with reasonable efficiency leaving from an origin and arriving at a destination. Motion, energy and routes are generic keywords for a guided vehicle. Their interrelationship is depicted in figure 2.

Of course, in order to complete a transportation system, there should be arrangements for load transfer, planning and scheduling of the vehicle operation. They will not be treated in this paper.

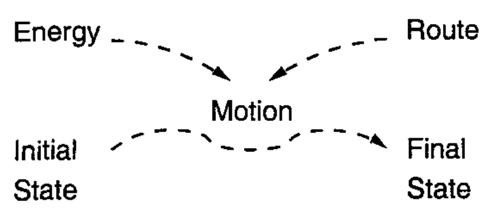

Fig. 2. Fundamentals for vehicle guidance

2.1 Motion

If we express the state of a vehicle with the symbol q (i.e. the configuration space of the vehicle in its environment), then motion is the fundamental means to achieve a transition from an initial state q_0 to a final state q_1. The continuous-time derivate $\dot{q}$ expresses the motion of the vehicle. The discrete-time difference Δq is sometimes more appropriate.

Although a vehicle may have many wheels and steering joints, expressed in a many degrees-of-freedom model, the motion of a vehicle is and can be sufficiently expressed in only a limited set of variables.

2.2 Energy

There is a direct relation between motion and kinetic energy. Moreover, the loss of energy is directly related to the kinetic energy. Therefore, efficiency is achieved by minimising the kinetic energy.

$$E_{kinetic} = \int_{t_0}^{t_1} \dot{q}^T W \dot{q} dt \tag{1}$$

Efficient motion of a vehicle also corresponds to consistent motion of a vehicle. Therefore, the steering angles and rotation of the wheels are strongly related to the planar motion of the vehicle. Usually, the steer angles and the wheel rotation are omitted in the configuration space of the vehicle.

2.3 Routes

Often, the desired state transition between the origin and the destination is precomputed. Moreover, the optimal state transition may not be obeying constraints set by the operating environment. Therefore, a route is used to express the preferred state transition of the vehicle in configuration space.

We express the route by two functions:

$$f_{geometry} : s \rightarrow q \tag{2}$$

and

$$f_{schedule} : t \rightarrow s \tag{3}$$

the geometry and the schedule respectively and t representing time and s representing a path variable. The execution of a route is the cascading of these tho functions.

If a vehicle deviates from this route, corrective actions will be taken causing additional loss of energy. So the guidance of a vehicle along a route can be seen as an optimisation problem minimising the loss of energy while making a state transition from the departure state towards the arrival state.

3 Architecture

Given the fundamentals treated in the previous section, an architecture for a vehicle controller is presented. This controller is suitable for both manual control and automatic guidance of vehices.

The first subsection shows how a tree layer architecture makes the connection between on one side fundamental concepts of routes and motion, and on the other side a specific configuration and instrumentation of a vehicle. The next three subsections are about each of the layers.

3.1 Control layers

A three layer architecture (figure 3) is based on the concept that motion of a vehicle can be described by only a limited set of variables. The top layer is completely generic and is the home for manual control and automatic guidance algorithms. The middle layer is the place where generic motion is mapped to the degrees-of-freedom of a specific vehicle. The bottom layer is the place where the degrees-of-freedom are associated to the physical inputs and outputs of the vehicle. From the tracking layer point of view, the two lower layers can be regarded as a motion servo system. It appeared to be possible to eliminate the specific dynamic behaviour of steering and driving systems in the vehicles. All vehicles respond in a similar fashion on the top layer motion setpoints (within their physical limitations).

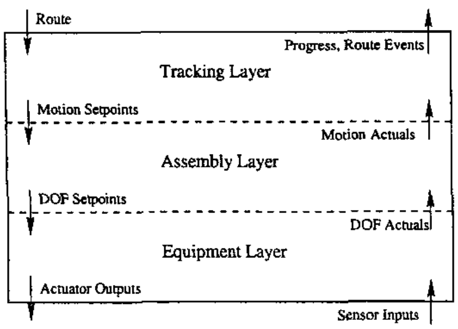

Fig. 3. A three layer architecture

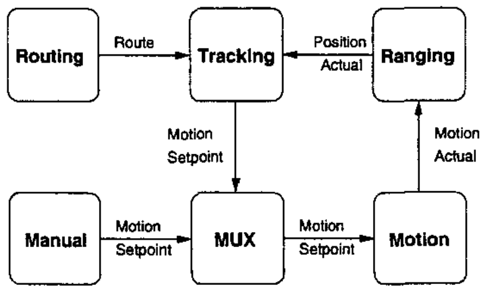

Fig. 4. Modules for manual control and automatic guidance

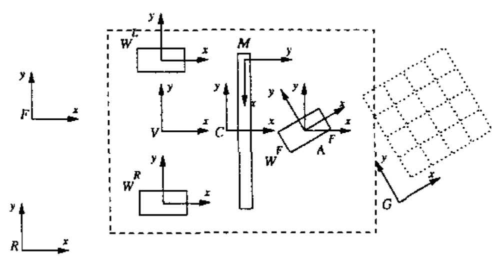

Fig. 5. Co-ordinates systems in a three-wheel vehicle

3.2 Modules and connections

A simplified breakdown of the top layer is presented in figure 4. The mechanisms for integrity control and reactive behaviour of the vehicle controller are neglected for clarity.

The routing module accepts commands in the form of elementary route sections and merges them to a path suitable for the tracking module. The tracking module accepts position actuals from the ranging module and route information from the routing module to compute motion setpoint to be sent to the motion module. The ranging module combines motion actuals of the motion module and measurements of position sensors to an accurate and reliable estimate of the vehicle's position and orientation (the position actual). The motion module accepts motion setpoints and returns feedback information in the form of motion actuals. The manual module accepts user inputs for steering, driving and brakes. The inputs are converted to motion setpoint depending on the selected steering and driving mode and suited for the motion module. Manual control and automatic guidance are chosen simply by a multiplexor for motion setpoints.

3.3 Assemblies and degrees-of-freedom

This layer is built about a robotic model of the vehicle in its environment. This model is represented by a tree of assembly nodes. Each node represents a co-ordinate system. Child nodes are defined with respect to their parent node with a set of degrees-of-freedom.

The robotic model is used to determine the relation between the variables of the configuration space and the various degrees-of-freedom present in the model. A set of generic matrix algorithms use this relation for motion estimation and control. As an example a model of a three-wheel vehicle is considered (figure 5). The degrees-of-freedom of a node define the relative position and orientation of this node with respect to the parent node. A path through the assembly tree from one node to another node will result in the desired co-ordinate transformation needed to map points from one representation to another.

The nodes in the example are abbreviated by capital letters and have the following meaning:

- R - the root node represents the reference co-ordinate system
- V - the vehicle, origin of vehicle co-ordinate system
- F - the floor, origin of floor co-ordinate system
- G - the grid, origin of grid co-ordinate system
- M - the magnet sensor, origin of magnet sensor co-ordinate system

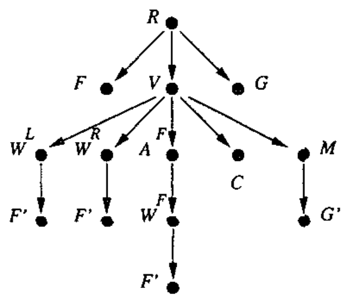

Fig. 6. Tree representation of a three-wheel vehicle

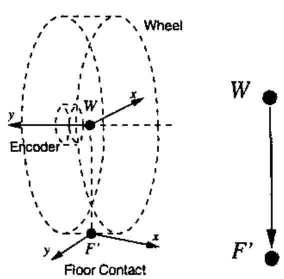

Fig. 7. Geometric model and tree representation of a wheel

- C - the center of gravity, center of gravity of the vehicle
- W^L, W^R, W^F - the wheels (left, right, front)
- A^F - the steer axle of the front wheel

A set a magnets is defined in the grid co-ordinate system. They can be detected by a magnet senser in the vehicle. In the tree representation (figure 6) some primed letters appear. These letters represent nodes that correspond to the node with the letters without primes. For example, F' is the floor under a wheel, and corresponds to the floor node F.

3.4 Equipment and devices

In the bottom layer, the idealised degrees-of-freedom are associated to physical inputs and outputs of the vehicle control system. This is achieved in two steps.

In the first step equipment models are used to associate degrees-of-freedom to sensors and actuators present in the vehicle. All sensors and actuators are converted to unified physical quantities needed for the degrees-of-freedom present in the assembly layer.

For example, consider the degrees-of-freedom between a wheel center and the floor under the wheel (figure 7). The longitudinal wheel travel (unit meter) could be measured by a quadrature pulse shaft encoder mounted on the wheel axle.

The equipment model models the relation between the longitudinal translation degree-of-freedom Δx and the number of counts Δn measured by a quadrature pulse encoder counter.

$$\Delta x = \frac{2\pi R_w}{n_{cpr}} \Delta n \tag{4}$$

Where R_w is the effective wheel radius and n_{cpr} the number of encoder counts per revolution.

The next step associates the digital quantities present in the control system to the physical interfaces present. Thus, analog inputs, analog outputs, encoder inputs directly connected to the controller or accessable through a field bus system can be used identically.

In this example, the encoder count can be interfaced directly by a counter register present on the vehicle controller. However, it is also possible that a quadrature encoder is present as a CAN-node, requiring additional services (configuration and node-guarding)

4 Conclusions

Based on the fundamental concepts of motion, energy and routes, an architecture for a generic vehicle controller is presented in this paper. This architecture appeared to be very powerful to realise automatically guided vehicles that differ very much with respect to eachother.

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References

[1] FROG Navigation Systems BV, http://www.frog.nl, e-mail: aartjan@frog.nl

[2] Advanced Public Transport Systems BV, http://www.sre.nl/hov, e-mail: phileas@hetnet.nl