Abstracts of Papers

WIRE-REFERENCE CONFIGURATIONS IN VEHICLE LATERAL CONTROL

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Lateral control is an essential function for all forms of individual automated ground transport. This paper reviews two aspects of such control: the magnetic field distributions associated with a guideway-based, wire-reference configuration and the associated vehicle-based sensors.

Two wire-reference schemes have thus far been suggested. In the first, the amplitude characteristics of the magnetic field are used to obtain the lateral control signal. In this paper, a theoretical analysis and detailed field measurements are used to define both ideal characteristics and those that would be encountered in a realistic operating environment. The resulting problems, which involve amplitude distortions of the field due to the proximity of steel-reinforcing materials, are defined, and their effects on vehicle control (poor tracking and passenger discomfort) are discussed.

In the second approach, the lateral control signal is primarily dependent on the phase characteristics of the magnetic field. A theoretical analysis and a corresponding experimental field study indicated that the problems associated with the first approach were largely overcome, as evidenced by successful full-scale tests of an automatically steered vehicle.

Sensors that derive lateral position information from the amplitude distribution of the magnetic field produced by a wire reference system suffer the following deficiencies: (a) the slope of the indicated position characteristic, and consequently the controller gain, are dependent on the magnitude of the current in the wire; and (b) conductive sheets of reinforcing or structural materials underlying the surface of the guided path can distort the shape of the indicated position characteristic. Observed distortion effects have ranged from a variation of the slope of the position characteristic with longitudinal position to a lateral shifting of the indicated lane center (null shift).

Successful high-speed, closed-loop control of an instrumented vehicle has been achieved by using both a one-wire and a two-wire reference with amplitude-sensing sensors. In both cases the tests were conducted on a section of highway constructed with laterally symmetrical reinforcing. Automatic guideway control was used to reduce the effect of longitudinal position varying gain.

Subsequently, operations were transferred to a section of highway constructed with laterally asymmetrical reinforcing, called continuously reinforced pavement. The null shifts, sensed by the one-wire amplitude sensing configuration, were so numerous that closed-loop operation was impossible at speeds higher than 48 km/h (30 mph). The field distortion caused by this reinforcing geometry was judged to be the worst encountered.

Since a practical reference-sensor system must perform well on all types of construction, the phase-sensing lateral position measurement technique was developed in an attempt to overcome null shift as well as gain change types of distortion. A vehicle was equipped with a sensor based on this technique, and closed-loop tests using a one-wire reference were conducted. The tests were highly successful in that a comfortable ride and excellent tracking accuracy of ±25.4 mm (±1 in) were obtained at speeds of more than 129 km/h (80 mph). These results were obtained on the same section of continuously reinforced pavement on which not even a 48-km/h (30-mph) closed-loop operation using an amplitude-sensing position sensor was possible. In my opinion, the phase-sensing technique represents a major advance in distortion-immune lateral position sensors.

AUTOMATIC LATERAL CONTROLLERS: SINGLE-LOOP CONFIGURATIONS

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The design of a single-loop configuration for vehicle automatic lateral control is presented. First, a path-dependent coordinate system for describing vehicle motion is defined, and the availability of motion quantities for use in such control is considered. The basic requirements of lateral control—accurate tracking on all expected geometric configurations, good response to disturbance inputs, and passenger comfort—are enumerated with respect to a control structure, which includes the derived dynamics of a typical U.S. passenger sedan. Various designs, in which different types of compensation are used, are evaluated in terms of the stated requirements, and attractive candidates are specified.

Subsequently, one controller design was tested under full-scale conditions. Here, a dual-mode test vehicle was automatically steered on both straight and curving roads at speeds as high as 129 km/h (80 mph). A wire reference system was used, and the concrete road was continuously reinforced. The maximum tracking error observed was 0.0635 m (0.2 ft) and occurred both when a sidewind was present and when the vehicle entered a curving section of roadway.

OPTIMAL LATERAL CONTROL FOR DUAL-MODE VEHICLES

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The lateral guidance problem for automated highway vehicles on an essentially straight roadway is considered in the light of optimal control theory. An optimal system regulator was designed by using a simple fourth-order, seven parameter, linear model of vehicle lateral dynamics and a quadratic performance index that penalizes both the vehicle's lateral displacement from the desired path and the vehicle's lateral and yaw accelerations. The initial condition response dynamics of the controlled model were investigated, and the importance of considering the vehicle's yaw acceleration when designing the regulator is shown.

Putting the model and regulator problem in dimensionless form reduced the number of independent vehicle parameters to four. The coefficients of the linear feedback law relating the vehicle's front-wheel steer angle to the model state variables are presented in dimensionless form for an extensive range of the four vehicle parameters. For a specific vehicle, the longitudinal velocity is the only parameter that varies significantly. However, the effect of longitudinal velocity on the feedback coefficients is accurately approximated by simple functions. These results are illustrated in the paper for a typical sedan.

LATERAL CONTROL OF DUAL-MODE VEHICLES

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The General Motors dual-mode vehicle is controlled laterally in the automatic mode in three ways. Primary guidance is achieved through front-wheel steering in a response to vehicle-borne computer control. Cables buried in the guideway surface generate a magnetic field for lateral reference. Vehicle-mounted antennae measure the deviation from the desired path, and the computer converts this signal to a steering correction signal, which in turn is magnified hydraulically in the steering mechanism. An independent mechanical backup, consisting of a vehicle-mounted arm and a slot in the guideway surface, is provided for positive switching in the diverge areas. The design of the guideway walls provides a second backup for lateral vehicle restraint.

The effects of feedback paths, control system design, and vehicle dynamics on disturbance response and path following are discussed. Vehicle directional control characteristics necessary for automated steering are described. The effects of selected component failures on vehicle lateral control are shown in the paper, and the influence of the lateral control system on the design of the guideway is indicated.