AUTONOMOUS INTELLIGENT CRUISE CONTROL (AICC) FOR PSA PEUGEOT CITROËN CARS : A PROMETHEUS PROJECT.

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***Abstract** : Autonomous Intelligent Cruise Control (AICC) is an assisting system for controlling the relative speed and distance between two vehicles in the same lane. It permits to drive at a constant given speed in Highwaw free of traffic, to maintain a constant distance with the vehicle ahead, to recognize a non moving object on the lane and stop before collision, to stop and go in heavy traffic. In the frame of a Prometheus project, car maker PSA Peugeot Citroën, has developed and carried out on an experimental vehicle a AICC system. A public presentation has been done in october 94 during final presentation of the Prometheus program in Paris.*

1. Introduction

Basically, the AICC system helps and replace the driver in the longitudinal control task. For this purpose, it manages the observation-decision-action control loop ordinarily performed by the driver. The driver for psychological comfort and safety reasons should be able to override the decisions of the system at any time by acting on throttle or brake. The AICC system is the reply to the customer wishes wich could expressed [2] as follows: " I would like to drive at a constant given speed when the highway is free of traffic, to maintain a safe distance if a vehicle preceeds mine, to be able to overtake it and come back automatically to my cruising speed. In heavy traffic conditions, I would like to automatically stop and go assuring always a safety margin. In all conditions, I would appreciate being reminded the safety regulations. The system should be totally dependable and at any time controllable by the driver". It appears that the objectives cannot be separated of their usage context. To reach theses objectives, the necessary components must operate independently of the traffic conditions.

2. System components

A Peugeot 605 (3.0 l, 6 cyl, automatic gearbox) has been chosen for this project. The cruise control loop needs a speed sensor; the throttle is controlled by a specific actuator (HELLA). The distance control (in fact a speed control with variable set point) uses a Laser range finder and is acting on speed set point or ABS brake regulation (BOSCH). The system basic specifications are:

Acceleration: up to 1.5 - 2.5 m/s^2

Deceleration: 0.5 to 1 m/s^2 by throttle lifting and 0.5 to 10 m/s^2 with brakes.

Interfacing with the driver requires both to display information from the sensors and the environmment and to allow for the driver control at any time. An alphanumeric display shows the vehicle state (speed and environment target), and a synthetic voice gives safety regulation information. A cruise control selector allows the driver the choice of operative function; AICC mode allows a transparent action from the driver.
The control problem is quite straight forward and its practical implementation in presented in Fig 1. In this paper we present the two most important points the speed control and the Kalman filter used for target validation.

3. Speed control.

The speed control is divided in two levels; the first level acts only on the throttle and the second (when the difference between actual and expected speed value is greater than a threshold) uses brakes. For the first level, the major difficulty is due to the road profile whose effect is as important as gas pedal. A classical PID regulator cannot be used; a control loop using a predictive internal model has been chosen for its robustness [4,5,6] and is presented in figure 2.

A simple car model can be given as a variable first order system:

$$y_m(k+1) = a_m \cdot y_m(k) + b_m u(k) \qquad (1)$$

with y_m the model speed, u the throttle angle.

$a_m = \exp(-T/\tau m)$ $\qquad$ $b_m = K_m(1-a_m)$

with:
T, sample period and τm time constant of the first order system.
K_m model steady-state gain
The a_m and b_m values have been determined by identification from experiments carried out on the actual car.

We have chosen a first order exponential reference trajectory for the speed evolution :

$$y_r(k+1) = \lambda . y_p(k) + (1-\lambda)u(k) \qquad (2)$$

with:
$\lambda = \exp(-T/\tau e)$
y_p measured car speed,
τe expected time constant.

Assuming u(k) remains constant during a prediction horizon H, the coincidence betwen y_m et y_r at time H will be obtained thanks to the following control [5]:

$$u(k) = K\left(y_{sp}(k) - y_p(k)\right) + \frac{1}{K_m} y_m(y) \qquad (3)$$

with: $K = \dfrac{1-\lambda^H}{K_m(1-a_m)}$

y_{sp}: set point car speed.

This leads to the speed control scheme of fig 2 which can be transformed on fig. 3 with a controler defined by:

$$C(z) = \frac{1-\lambda^H}{K_m\left(1-a_m\right)}\left[\frac{z-a_m}{z-1}\right] \qquad (4)$$

with $z = e^{Tp}$
The discrete controler transfer function shows an integrator avoiding static error.
To take into account the specific non-linear model of the throttle actuator HELLA, an internal loop has been set up using throttle angle measurement. The sample period is 22 ms.

The second level of speed control is triggered when a deceleration greater than $1 m/s^2$ is needed. The brake actuator BOSCH owning a control internal loop, it accepts a decceleration set point.

Distance control
A minimum following distance is determined by:

d = max[dmin,k.V1]

with: dmin = 2.5m for stop and go traffic.
The speed set point module (ie fig 1) determines the set point value (calculated from safety distance or chosen by the driver) according the target identification.

Figure 4 shows a speed control experiment carried out with variable set point due to the distance control. The control loop has been tuned (with τe) to satisfy comfort criterion.

4. Target Identification

The problem of target following is fairly easy to solve as the target identification and its distance measurement can be followed by its speed estimation. Thereafter a safety distance table, function of the speed will determine the set point speed of the vehicle which is assigned to the vehicule cruise control system. Difficulties met are of several order. The sensor plays both role of target identifier and distance measurement, and in some cases the target is lost due to the pitch angle of the car or the presence of bends.

To solve these difficulties, it is necessary to introduce a target validation module which is constituted of a Kalman filter and a set of hypothesis testing.

4.1. Kalman filter

The laser sensor brings measurement distance d(t) and relative speed of a target; adding V1, (the car speed), we obtain the target speed V2. The Kalman filter estimates $\hat{d}$, $\hat{V}1$ and $\hat{V}2$ using a state representation model of the dynamic system constituted of the car following a target.

$$\dot{d} = V2 - V1 \qquad (5)$$

$$M.\dot{V}1 = F_E - F_B - F_A \qquad (6)$$

with: F_E Force due to Engine,
F_B Force due to Brake
F_A Aerodynamic Force
M vehicle mass

The aerodynamic force is modelled by:

$$F_A = \gamma.V1^2 + \delta.V1^3 \qquad (7)$$

Using a first order development around a reference speed V_{01} to linearise (7), we obtain:

$$\begin{cases} \underline{\dot{x}}(t) = \begin{pmatrix} 0 & -1 & 1 \\ 0 & \Omega & 0 \\ 0 & 0 & 0 \end{pmatrix}.\underline{x}(t) + \begin{pmatrix} 0 & 0 \\ 1/M & -1/M \\ 0 & 0 \end{pmatrix}.\underline{u}(t) \\ \underline{y}(t) = \underline{x}(t) \end{cases}$$

with $\underline{x}(t) = \begin{pmatrix} d(t) \\ V1(t) \\ V2(t) \end{pmatrix}$ $\quad \underline{u}(t) = \begin{pmatrix} F_E(t) \\ F_B(t) \end{pmatrix}$

and $\Omega = -\dfrac{\gamma.V_{01} + \delta.V_{01}{}^2}{M}$

This model indicates that $\dot{V}2 = 0$; but its value is modified by the Kalman filter. The value of Ω shows that this term must be modified at each sample.
In the input vector $\underline{u}(t)$, F_E is linked with the throttle angle by a static relation using engine torque mapping and gearbox ratio. For F_B, an actuator BOSCH accepts expected deceleration as input signal.

The discretization of this model leads to:

$$\begin{cases} \underline{x}(k+1) = F.\underline{x}(k) + G.\underline{u}(k) + \underline{w}(k) \\ \underline{y}(k) = C.\underline{x}(k) + \underline{v}(k) \end{cases} \qquad (8)$$

with:
F,G discretization of matrix A and B,
$\underline{w}(k)$ structure white noise vector,
$\underline{v}(k)$ measurement white noise vector.

We note the variance covariance matrix:

$$Q = E\left[\underline{w}(k).\underline{w}(j)^T\right] \text{ and } R = E\left[\underline{v}(k).\underline{v}(j)^T\right]$$

supposed diagonal.
It is assumed that the $\underline{w}$ and $\underline{v}$ noises are independant.

$$E\left[\underline{w}(k).\underline{v}(j)^T\right] = 0$$

A classical Kalman filter [7] has been used, defined by:

$$\underline{\hat{x}}(k+1/k) = F.\underline{\hat{x}}(k/k) + G.\underline{u}(k) \qquad (9)$$

$$P(k+1/k) = F.P(k/k).F^T + Q \qquad (10)$$

$$K(k) = P(k/k-1).C^T\left[R + C.P(k/k-1).C^T\right]^{-1} \quad (11)$$

$$\underline{\hat{x}}(k/k) = \underline{\hat{x}}(k/k-1) + K(k).\left[\underline{y}(k) - C.\underline{\hat{x}}(k/k-1)\right]$$

$$P(k/k) = P(k/k-1).\left[I - K(k).C\right] \qquad (13)$$

with:
K(k) evolutive gain matrix,
P(k) evolutive variance covariance matrix.

The matrix P has been initialized on its diagonal from measurement values.

It has been verified through simulations that K(k) reaches a constant asymptotic value. To simplify implementation this constant asymptotic value has been used at each sample so that equation (11) is not necessary.

The target behavior being unknown, it has been modeled in the Kalman filter as follows:

$$\hat{V}2(k+1/k) = \hat{V}2(k/k) + \frac{V2(k) - \hat{V}2(k/k-1)}{\sqrt{R(3,3)/Q(3,3)}}$$

The previous value is updated by the difference between measured and filtered value weighted by noises. Figure 5 shows the effect of Kalman filter on speed V2. The solid line represents the measured value and the dotted line the filtered one.

4.2. Hypothesis testing

The distance measurement can be disrupted by short losses of target. Basically, hypothesis testing verifie if a signal remains coherent with its statistical properties (average, standard deviation).

In this application, the goal is to detect an abrupt change in distance measurement.
The difference betwen filtered and estimated distance value is built and this signal is a zero average and normaly distributed variable.
Here the two hypothesis are normal measurement or abrupt change of the average. Many tests are modifications of the likelihood ratio test [9]. In an on-line framework, the basic problem to be solved is the detection of a jump greater than 4m (car length) in the average distance measurement as quickly as possible. In most applications, an excessive number of false alarms are not accepted by the users, and on the other hand, missing faults could have dangerous consequences. A way to choose the probability of false alarm independent of the missing fault one is to use Probability Ratio Test (SPRT). With sequential tests, detection is not complete at each sample time, but after analysing many samples if more statistical information is needed. So, the test is characterized by a delay of detection.
The result of hypothesis testing is shown on figure 6. At time t=36s, a bad measurement is detected and replaced by the filtered value. At t= 39s, the target leaves the lane; an abrupt change is detected but after a delay, the filtered value reaches the measured distance. As it can be observed, a new target is detected at t=44s and the same delay is necessary between filtered and measured value. A trade-off has been found betwen a short delay and a safe measurement.

5. Conclusion.

This paper describes an AICC structure which has been tested on actual car. The whole strategy has been implemented in a on board computer. A display gives to the driver the following information: target distance and speed, set and actual speed. Actually, research on different sensors is made; a radar is tested to be used as distance sensor due to an unsufficient reliability of the lidar.

The most important module with respect to the dependability of the system is the target validation module wich actually senses the outside world.

The next step is an implementation on a Citroën car making full use of the hydraulic system which enables a direct implementation of thebraking stategy.

The intelligent cruise control system is one of the most interesting one in the current technological developments because not only does it involves the car as a system within the traffic but also its design necessitates an integrated approach.

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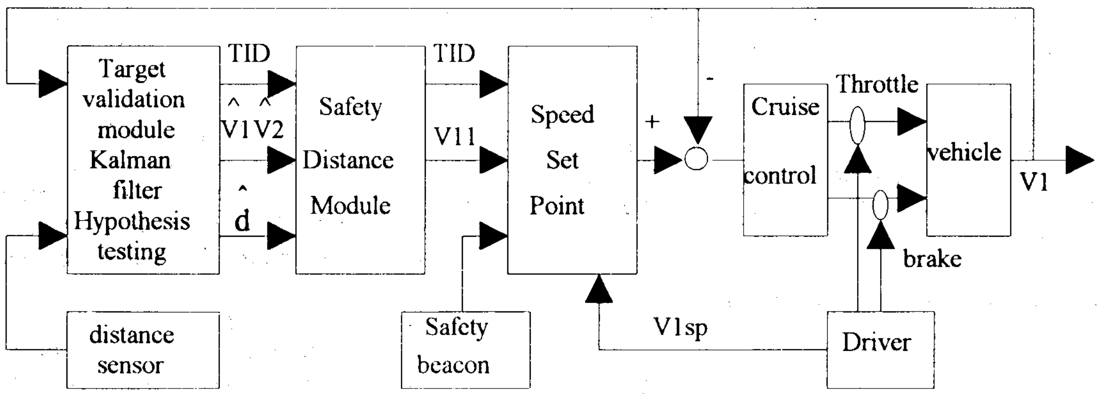

Figure 1. Functional block diagram of the AICC system.

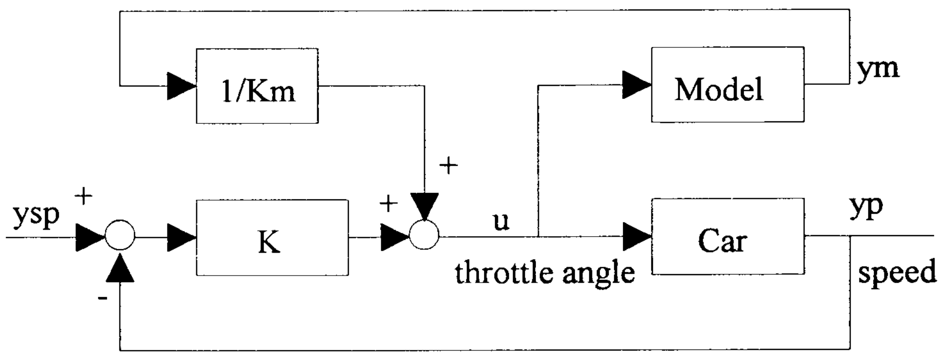

Figure 2. Speed Control loop using predictive internal model

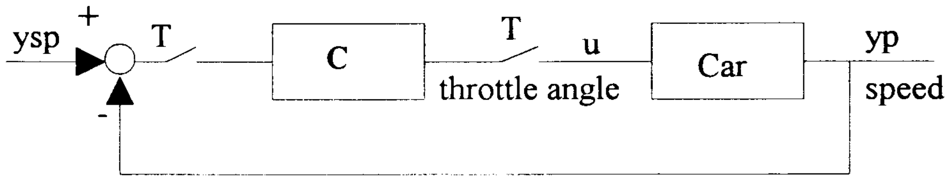

Fig 3. Speed control equivalent scheme

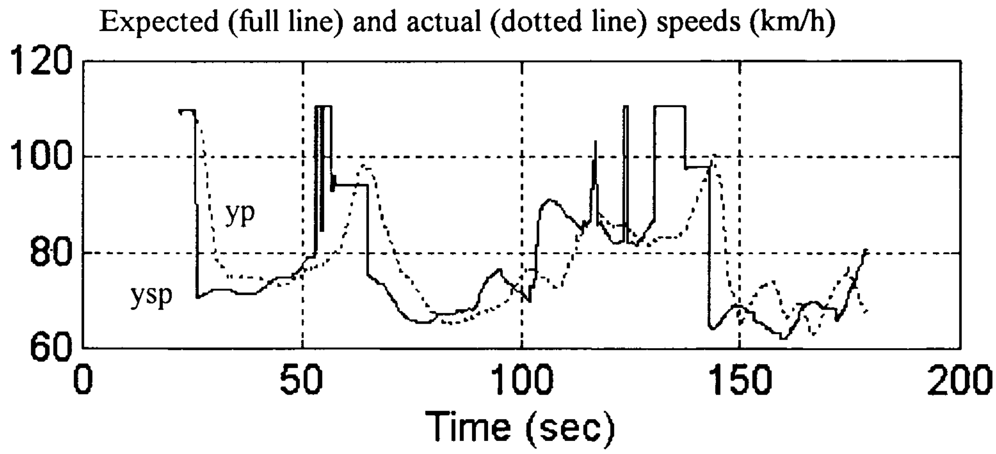

Fig 4. Speed control experiment result

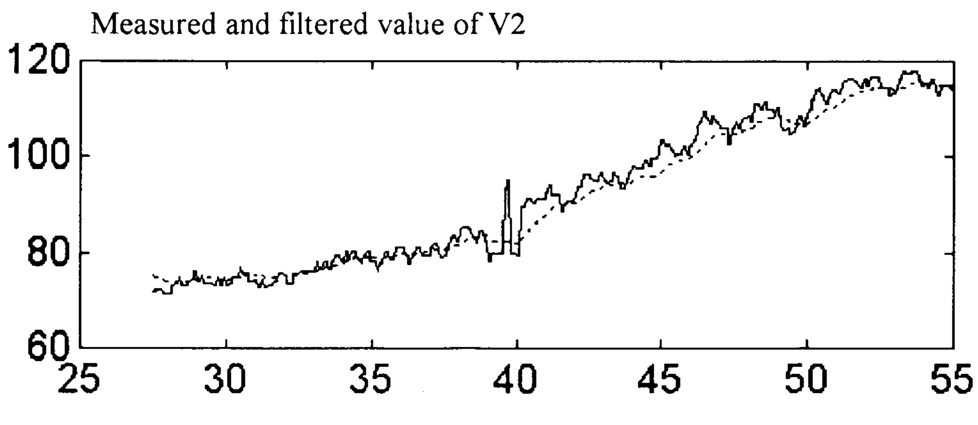

Fig 5. Effect of kalman filter on speed V2

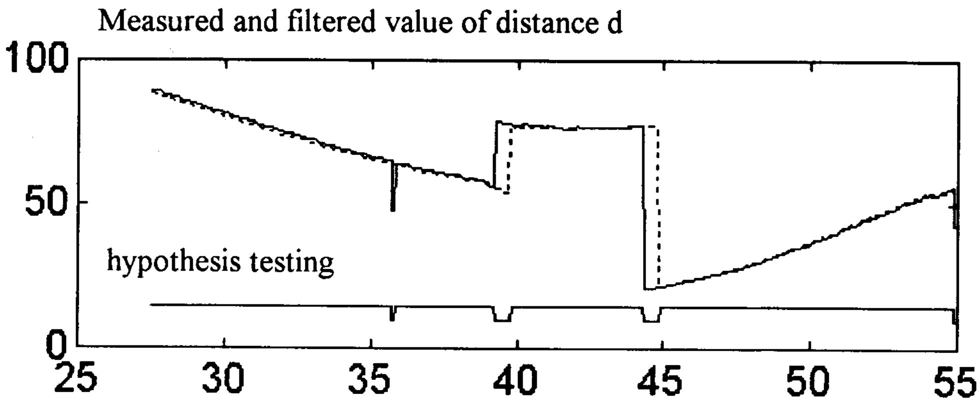

Fig 6. Target validation using Kalman filter and hypothesis testing