Automatic Guided Vehicles in Agricultural and Green Space Fields

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Abstract

Working on new equipments to increase agricultural productivity and safety, reducing human action hardness, Cemagref and Lasmea have developed an help guidance system for agricultural vehicles. The aim of this system is to help the operator to guide the machine in order to give more attention to the order task. To reach this goal, we use a visual perception of the environment because this sensor gives a solution well adapted to lots of situations. This project began with researches on a visual guidance system for a lawn mower in 1990 and has been adaptated to the development of the same system for a combine harvester in 1995. We model the lawn mower with a virtual axle, use trajectory generation to guide it, and localize the vehicle at each iteration to insure the servoing task. For the combine harvester, we decide to use the **task function approach** *[23] and then to control the combine harvester directly in the sensor space.*

1 Introduction

Many guiding applications can be found in agricultural cycle and green space environment. For instance, we can cite mowing the lawn, cultivation, seeding, fertilization, plant protection, harvesting, forage work (straw,hay), ... The machines are adapted with the applications, and we find mower, tractor, combine harvester. In theses applications the environment is partially structured and characterised by an initial path and successive guiding/following paths.

The perception problem to solve the guiding task, is to detect for instance a furrow in the ground (Till work), a reap limit between mowed and unmowed part (Harvest work), a haycock, a strawcock (Forage work) ... For that, many sensors can be used like video camera, ultrasonic sensor, laser telemeter sensor or mechanical sensor.

Some applications has been done in agricutural field, particularly in harvesting [2, 21], in mowing the lawn [20, 5, 6, 3], in collecting tree fruits [1, 25], in tomato cultivation [24], and many others ...

We have been interested on the reap limit detection by vision to guide a lawn mower and a combine harvester. In the first part of this paper, we present briefly the perception problem and some results obtain with pictures of grass and weat. In the second part, we develop successively the modelling and the control aspect of the first application. The modelling use a virtual axle with two wheels, and the control is insures by trajectory generation. Finally in the third part, we follow the same presentation for the second application. We use pole asignment technique to design the controller directly in the sensor space.

2 Perception aspect

In our applications, the aim of the perception part is to detect the reap limit between cut and uncut crop.

We use an image segmentation based on 4 parameters [5]:

- two parameters of texture (homogeneity, entropy) were chosen using the cooccurrence matrices (texel: region of size 16×16 pixels [11].
- two parameters are computed from local grey-level histograms (the maximum, and the second order of moment of grey-level histograms).

The segmentation is unsupervised and uses the *Markov field modelling* [10, 26, 1]. The algorithm permits the extraction of lines candidates for the reap limit and the selection of the line which represents the situation between the vehicle and the reap limit ((θ, d) parameters) (see figure 1).

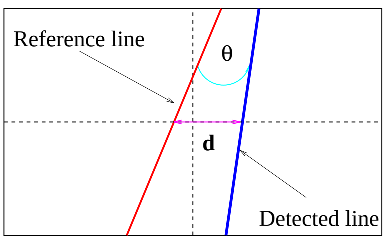

Figure 1: Modelling the scene in image space

For more details of this algorithm, you can see [4, 6, 7].

Figure 2 gives some results of detection in presence of grass and weat.

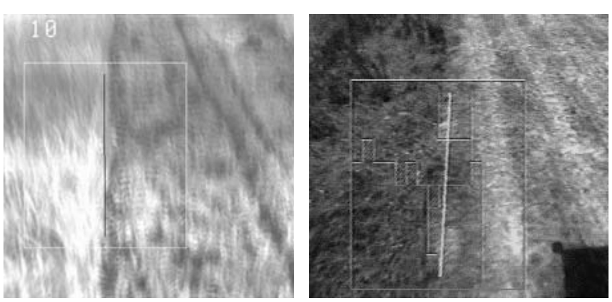

Figure 2: Crop line detection (grass and weat)

3 AGV in green space field

The application is to guide the lawn mower by vision in regard to cut and uncut limit. Two main aspects for this application has been treated:

- the vision/perception aspect by Derras in [4] which consists to detect the crop line and to extract the (d, θ) parameters.
- the control aspect by Debain in [2]

The mower is a professional lawn mower built by **Guerin Courde**. Figure 3 shows the prototype used in this application. This machine has four driven wheels and the gap is insured by the difference $V_2 - V_1$. V_1 and V_2 represents the speed of the center of both wheels.

Figure 3: The lawn mower

The modelling of the non-holonomous vehicle is made with a virtual axle (see figure 4) with 2 wheels.

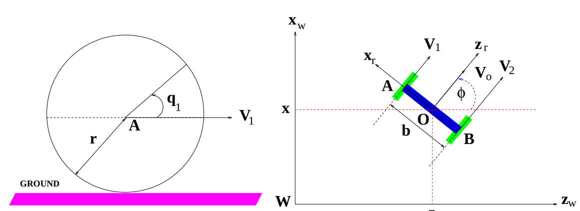

Figure 4: Modelling with a virtual axle

If V_1 and V_2 are constant, each point of this axle move on a circle with a radius R as :

$$R = \frac{v}{\dot{\phi}} = \frac{b}{2}\frac{V_2 + V_1}{V_2 - V_1} = \frac{b}{2}\frac{\dot{q}_2 + \dot{q}_1}{\dot{q}_2 - \dot{q}_1} \qquad (1)$$

So, we retain the following relation to characterize the kinematic of the virtual axle :

$$\left\{\begin{array}{lcl} v & = & \frac{r}{2}(\dot{q_1}+\dot{q_2}) \\ \dot{\phi} & = & \frac{r}{b}(\dot{q_2}-\dot{q_1}) \\ R & = & \frac{b}{2}\frac{\dot{q_2}+\dot{q_1}}{\dot{q_2}-\dot{q_1}} \end{array}\right. \quad (2)$$

r represents the radius of both wheels, $\dot{q_1}$ and $\dot{q_2}$ the angular velovities, v the longitudinal velocity and ϕ the orientation of the axle. In our application, the control variables of the mower are :

- $v = \frac{(V_2+V_1)}{2}$ which represents the average speed of both wheels
- $\Delta v = (V_2 - V_1)$ which represents the difference of both wheels velocities.

From the previous equations 2, we deduce

$$\left[\begin{array}{c} v \\ \Delta v \end{array}\right] = \left(\begin{array}{cc} \frac{r}{2} & \frac{r}{2} \\ -r & r \end{array}\right) \cdot \left[\begin{array}{c} \dot{q_1} \\ \dot{q_2} \end{array}\right] \quad (3)$$

To control the machine we generate a trajectory composed with 2 circles [14]. We consider two positions characterized by the difference in position (dx, dy), and θ the difference in orientation (see figure 5).

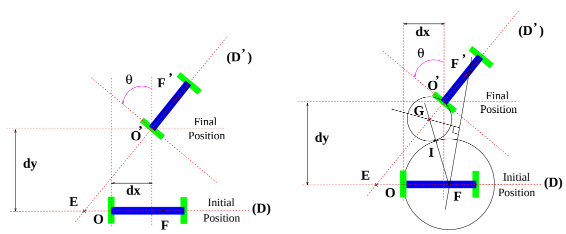

Figure 5: Trajectory generation

The main relation used to defined the trajectory are developed in [2]. Knowing the two angle and radius of the circle, we can determine the velocities to apply on the wheels:

$$\left\{\begin{array}{l} \dot{q_1} = \frac{V_{moy}}{2.R.r}(2.R - b) \\ \dot{q_2} = \frac{V_{moy}}{2.R.r}(2.R + b) \end{array}\right. \quad (4)$$

where $v = V_{moy}$ is the average speed of both wheels.

Using relation 3, we deduce :

$$\left\{\begin{array}{l} v = V_{moy} \\ \Delta v = \frac{b.V_{moy}}{R} \end{array}\right. \quad (5)$$

We have tested successfully this approach both in simulation and experimental cases. For instance, figure 6 shows the evolution of the position and orientation of the mower in presence of noise (20 pixels) on d parameter. More details on this application can be found in [2].

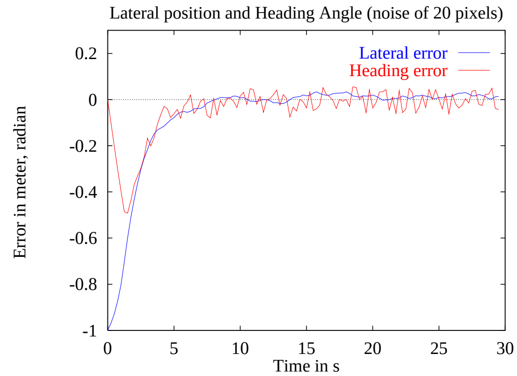

Figure 6: Position and Orientation with noise (20 pixels)

4 AGV in agricultural field

The application is to guide a combine harvester by vision in regard to cut and uncut limit. This is a collaboration with a european firm. The prototype is presented in the figure 7.

Figure 7: Our combine harvester

The vision aspect is similar to those encountered in green space environment. We use a machine with two steerable wheels, and two driven wheels. The model of the vehicle assumes that there are no flexible parts, the vehicle moves on plane surface, there is no translational slip between the wheels and the surface, and there is sufficient rotational friction between the wheels and the surface.

We consider the steering mechanism as the same as a bicycle (see figure 8).

Let $\dot{\psi}$ the angular velocity vector directed along the y axis, and $\dot{x}$ the linear velocity directed along x axis.

We find the kinematic model of the machine expressed by the following equations [15, 17]:

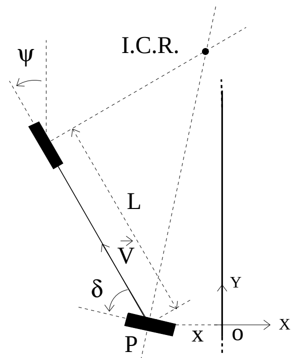

Figure 8: Bicycle model

$$\left\{ \begin{array}{l} \dot{\psi} = -\frac{V}{L}\delta \\ \dot{x} = V\psi \end{array} \right. \tag{6}$$

However, we only control the wheel angle δ. We can find an equation linking δ to the vector $(V, \dot{\psi})$.

In our application, we consider that the velocity V is constant, then we have [13, 19]:

$$\boxed{\delta = -\frac{L}{V}\dot{\psi}}$$

For the control, we have tested three approaches. Two of them are based on the *task function approach* [23] and the third is based on the neural networks. All the details are presented in [16]. In this paper, we summerize one of them using a pole assignment approach.

To establish the state model of the system, we first use the following relation [8, 12]:

$$\underline{\dot{s}} = L_{\underline{s}}^{T}\ T_c \tag{7}$$

which links the variations of the sensor signal $\underline{\dot{s}}$ to the motion apply to the sensor T_c through the interaction matrix $L_{\underline{s}}^{T}$. The interaction matrix or image jacobian is obtained by using the well known equation of optical flow measurement to $3D$ structure and motion in the scene [22, 9].

In our application, the scene is represented by a straight line and modelled by its projected line in the image frame (see figure 9). The position of the machine and its orientation is expressed according to the set of visual features $\underline{s} = (\theta, \rho)^T$.

We use the $\underline{s}$ as the state vector, and we find a state model which integrates both the model of the machine and that of the scene:

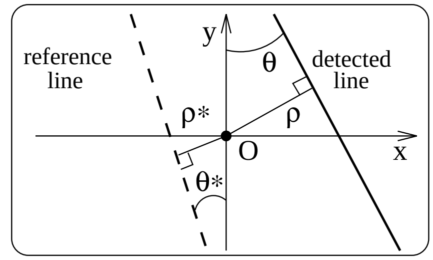

Figure 9: 2D camera frame

$$\underline{\dot{s}} = A\ \underline{s} + B\ \delta \tag{8}$$

where:

- $\underline{s}$ = the current visual information vector,
- δ = the control variable,
- A and B are constant matrices.

The control law is synthesized using a pole assignment technique (second order system having ξ as a damping ratio and ω_0 as its frequency).

In order to test the control law, we laid out a trajectory composed of a bend, a step of one meter and a straight line.

The vision system is composed of two VME microprocessor boards, and the image processing calculation time is about 200 ms (close to that encountered in a natural environment). We ajusted the gain of the controller by using the following characteristics of our closed system: $\omega_0 = 0.14rd/s$, $\xi = 0.9$, and $V = 20km/h$.

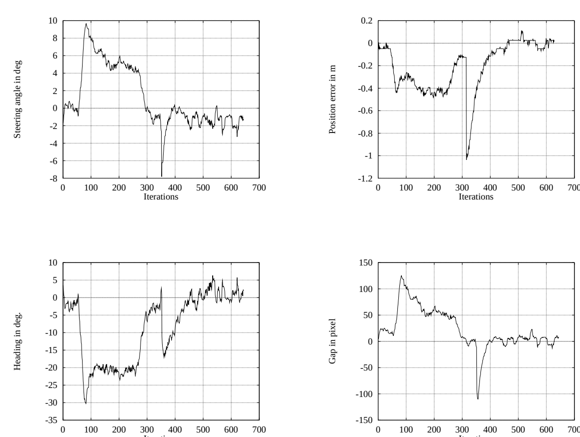

Figure 10: Test at 4 km/h ($\xi = 0.9$, $\omega_0 = 0.14rd/s$)

In the experimental test, we first follows the bend, then we passed the step of one meter and finish with the straight line. Figure 10 shows the differents curves.

All tests passed successfully, but we observed that this technique tends to cut the bend.

5 Conclusion and Perspectives

We have presented two systems that provide the driving assistance to agricultural mobile machine in order to help human beings in repetitive and difficult tasks in a natural environment.

The first application deals with vision-based control of a lawn mower. We compute a trajectory based on two circles, and insure the servoing of the mower by estimating the position and orientation of the vehicle at each iteration.

The second application is to guide a combine harvester. The controllers are designed in the image space. We have tested three approaches successfully. Two of them need the modelling of both the vehicle and the scene. The third one is a "black-box modelling" and needs a phase of learning

We have also design a controller which is able to guide the vehicle on a slope ground with an adaptative control strategy [18].

For the future, we investigate in two ways. The first is to improve the environment perception using others sensors like lasers telemeters and fuzzy theory to combine laser and video informations. The second is to developed $3D$ controllers using the kinematic GPS as the main sensor.

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