IQ99 – A MOBILE AUTONOMOUS VEHICLE

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Abstract: This paper presents a small autonomous mobile robot, designed to participate in the Robotic Contest of the *"1999 Festival des Sciences et Technologies"* – Classe Libre. The vehicle is modular, in the sense that new functionalities may be added if needed. Therefore, it can be used as a testbed for research and development on autonomous mobile robots. This robot integrates work of different areas, such as electronics for driving and steering motors, the design of mechanical structures to build a robust robot as well as the development of a fuzzy logic based navigation system.

Keywords: Mobile Robots, Guidance Systems, Navigation Systems, Image Processing, Fuzzy Systems.

1. INTRODUCTION

This paper presents the design and implementation of a small, autonomous, modular mobile platform, nicknamed IQ99.

IQ99 is the second version of a vehicle built in 1998 (IQ1), with the same mechanical and electrical structure. The platform was designed as a testbed for motor control, vehicle guidance and localization methods for mobile robots.

The vehicle has the ability to follow a track painted on the floor (see Fig. 1) and recover from a path loss. It can also collect and select billiard balls of different colors, placed on the floor along the track. The vehicle has the capability to abandon the track, head towards a post with a retro-reflector and a billiard ball on its top, throw down the ball, and finally recover the track.

In this project the authors designed suitable mechanical structures for the problems involved, built electronic solutions for speed controllers and motor drives, dealt with image processing software and used some guidance algorithms. All those are described in the following sections.

2. MECHANICAL STRUCTURE

The mechanical structure is divided in four main blocks: the chassis, the transmission, the ball catcher/selector and the throw-down-ball structure. Fig. 2 shows a main view of the robot.

2.1 Chassis

The platform is made of aluminum and BOSCH pipes, and was designed with modularity in mind, i.e., the chassis provides a solid support for the electronic boards, for the batteries and any other items to be added in the future.

The system is modular enough to optimize its functionalities. For instance, in the pure speed competition that took place in FST99, the ball catcher/selector and the throw-down-ball system were easily removed. This removal highly improved the vehicle performance in the pure speed competition.

The chassis is 40 cm long by 53 cm wide. Its height is 50 cm without the throw-down-ball system and 130 cm with the throw-down-ball system installed.

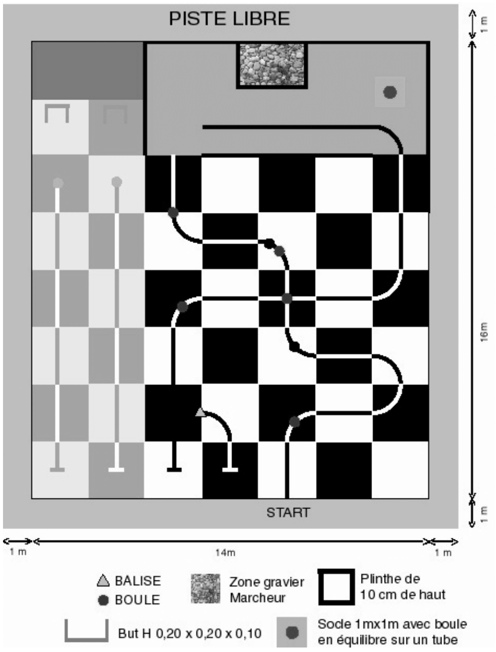

Fig. 1. FST 99 track.

The BOSCH aluminum pipes proved to be a good solution for building this kind of robots as they are very modular and provide a huge number of accessories for connections, to adapt motors, to build elevators, to connect driving pulleys and belts and so on. They were also a more efficient solution than those based on metal plate that were used in earlier editions of this contest (Aparício *et al.*, 1998; Lima *et al.*, 1998).

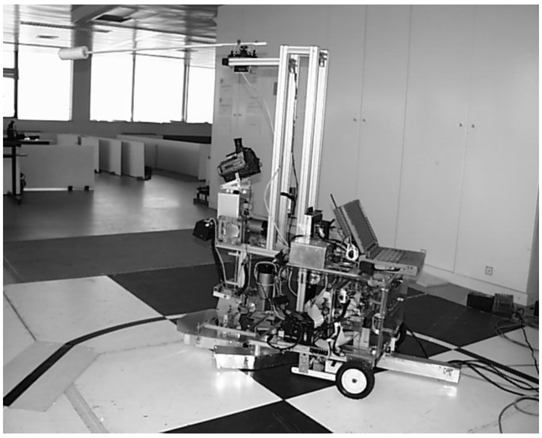

Fig. 2. IQ99 vehicle.

2.2. Transmission

The vehicle transmission consists of two DC motors: the traction motor and the steering motor.
The traction motor consists of a 12 V (90 W) DC motor, with a gearbox, that delivers 290 rpm and 1.9 N.m torque. The traction motor was dimensioned to speed up the robot till a 2 m/s speed considering a friction loss of 50% on the gearbox.
The steering motor consists of a 12 V (60 W) DC motor, with a gearbox, that delivers 100 rpm and 3.5 N.m torque. Due to structural restrictions, driving pulleys and belts were inserted between the gearbox output shaft and the wheels. The steering motor was dimensioned to turn 180 degrees in less than one second, considering the existing front wheel static friction that was experimentally measured.

2.2. Ball Catcher/Selector

This structure is made of aluminum and is placed under the car. See section 4.5 for more details.

2.3. Throw-Down-Ball Structure

This structure was specifically designed for the 1999 competition and gives to the vehicle the ability to throw down a ball, which is on the top of a post (see Fig. 3). The structure is made of BOSCH pipes and a rotating arm, made of aluminum, which is linked to a servomotor.

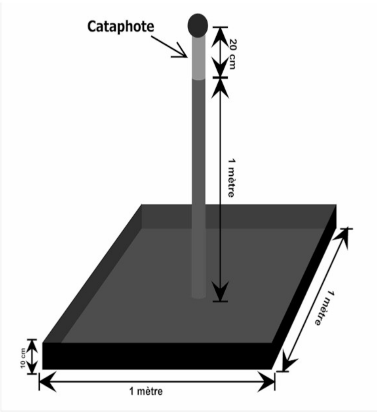

Fig. 3. Post with a retro-reflector and a ball on its top.

3. KINEMATICS

The vehicle has a tricycle-like structure. This leads to the following kinematics equations:

$$v = R\omega\cos(\alpha), \dot{\theta} = \frac{R}{b}\omega\sin(\alpha)$$

$$\dot{x} = v\cos(\theta), \dot{y} = v\sin(\theta)$$

where α is the steering angle, θ the vehicle orientation, R the wheel radius, v the velocity along the longitudinal axis, and ω the traction wheel angular speed.

The use of a tricycle-like structure was motivated by the independence between speed control and steering as opposed to differential structures were one motor on each wheel are responsible for both speed and steering control. The system is much more stable but unfortunately it induced a lot of extra work for building the Ball Catcher / Selector.

3. POWER SUPPLY AND POWER DRIVES

The vehicle power supply is divided in two blocks: the signal power (electronics) and the motor power. The independence between vehicle power and signal power is required to avoid spikes introduced by the motors in the power lines. These spikes, although short in time, have severe consequences in the signal electronics, leading to malfunctions.

The vehicle requires four batteries of 7Ah, placed under the chassis, inside special purpose drawers. Two of the batteries supply power to the two PCs on board through PS65 DC-DC converters. The other two batteries supply power to the steering and driving motors.

Another two small batteries of 1.3 Ah were introduced this year to supply to the modular electronic structure, the servo-motor of the look-ahead camera, the servo-motor of the ball selector and the servo-motor of the throw-down-ball structure. These batteries are placed on the back of the chassis.

4. HARDWARE ARCHITECTURE

4.1. The Image Processing System

IQ99 mobile robot uses two cameras to sense the track ahead and has the ability to process the information given by these two cameras, to follow the track, change the vehicle speed and determine the type of interruptions the robot is arriving at. This task of processing the image information is accomplished by the use of two Pentium computers. A local Ethernet network links them. Figure 4 shows the hardware architecture block diagram.

The guidance control computer has the job of processing all the information provided by the guidance camera, notably determining: track deviation and misalignment with respect to the robot longitudinal axis; whenever a track, a 'T', or an interruption exists in front of the vehicle. This information is used to send references to the steering motor controller.

The look-ahead vision computer processes the information given by the look-ahead camera. This camera gives the robot the ability to anticipate the interruption type (i.e., curve or straight line), hence the vehicle does not have to stop (theoretically) when it arrives at the interruption.

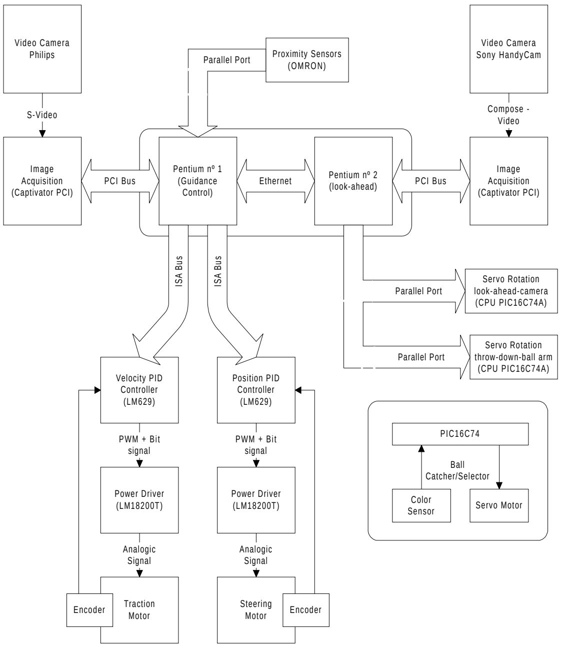

Fig. 4. Hardware architecture.

There are also some other sensors involved in the different tasks required by the competition rules, which are described in the sequel, together with details of the processing units and actuation systems (Astrom and Wittenmark, 1996).

4.2. The Processing Units

The mobile robot has two on-board PC motherboards, with 166 MHz Pentiums, 2x16MB of RAM, 1.2GB and 2GB hard drives, two network adapters and two video adapters. The first computer also interfaces a motor control board.

4.3. Sensor Systems

Track Sensors: The guidance camera is a Philips XC731/320. This camera is attached to the steering axis. The look-ahead camera is a commercial Sony camcorder, attached to the robot by a servo motor that can operate in various positions.

Ball Color: A pair of infrared (IR) emitter/receiver LEDs is used to discriminate between red and black balls.

Encoders: Encoders provide information on motor position (steering motor) and velocity (driving motor).

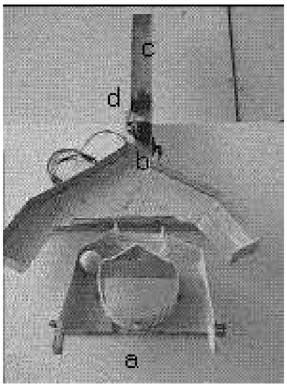

Fig. 5. Bottom view of ball catcher/selector: a) ball entrance, b) ball selector, c) container corridor and d) exit door.

Proximity Sensors: two IR proximity sensors are used to detect the post. One of them is used to detect the beacon on the post (see Fig. 3). The other detects the base of the post.

4.4. The Actuation System

There are two DC motors associated to the front wheel block unit: a 90 W driving motor with a gearbox reduction of 400:1, and a 60 W steering motor, both with a gearbox reduction of 100:1.

A motor control board, made by the team that participated in the contest in 1997, controls the motors. This board is based on two National LM629 motor PID controller chips that interface the guidance controller computer through the ISA bus. A PWM signal and a bit signaling the direction of the motor shaft rotation are output to each motor power amplifier.

Position set points for the steering motor and velocity set points for the driving motor are the board inputs, fed by the guidance controller computer.

4.5. Ball Catcher/Selector

The ball catcher/selector was specifically designed for this competition. This module catches billiard balls placed along the track and rejects some of them, depending on their color. The solution of the authors takes advantage of the forward motion of the vehicle. Views of the ball catcher/selector structure can be seen in Figs. 5 and 6. This structure is placed under the vehicle. The ball entrance section of the structure directs the balls to the ball selector. The ball selector is composed of a servomotor, which position depends on ball color. The ball container is a corridor designed to accommodate a maximum of seven balls.

The central unit of this module is a PIC16C74 micro-controller, which does the sensor reading and the servo actuation. IR LEDs were installed in a location before the servo to determine the ball color.

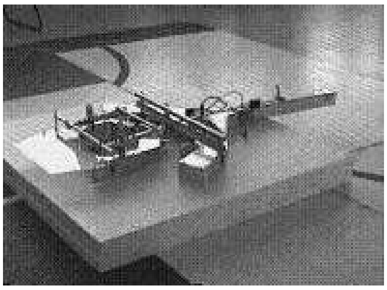

Fig. 6. Perspective view of ball catcher/selector.

5. SOFTWARE ARCHITECTURE

Each motherboard runs under Linux operating system. The reasons for this choice were the following: robustness, lightweight multitasking and networking facilities. Communication between motherboards is based on TCP/IP sockets (Stevens 1990).

Taking advantage of the multitasking operating system Linux, the tasks to be done were distributed by different processes communicating asynchronously. Fig. 8 shows the software architecture block diagram.

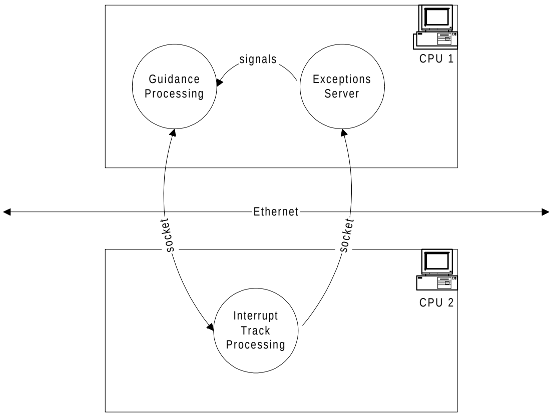

Fig. 7. Software Architecture.

6. FUNCTIONAL ARCHITECTURE

The robot functional architecture is depicted in Fig. 8. An additional supervisory level, not shown in the figure, takes the vehicle task through a sequence of states, related to the different subtasks (e.g., stopping the robot, planning and executing a virtual trajectory, activating the throwing device). State transitions are triggered by the occurrence of events such as the detection of a ‘T’, a track interruption, or the proximity of the post.

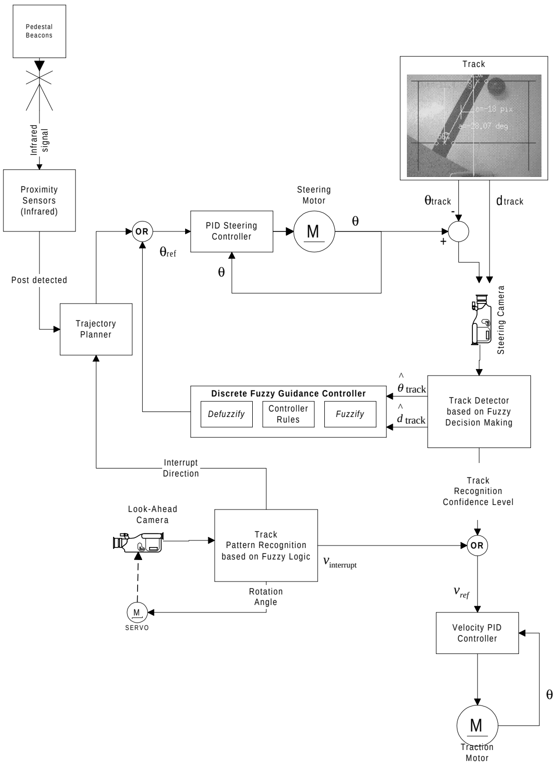

Fig. 8. Functional Architecture.

The vehicle navigation system is composed of two subsystems: track detector and track follower.

The track detector selects two image rows based on past information and classifies each row information based on three features: black/white contrast over the row, image edges strength and track width. Feature classification is based on fuzzy membership functions. A 1-D image derivative (Jain, 1989) is determined for each image row, and several pairs of derivative maxima and minima are graded with respect to the three features. The grading is subsequently combined by a fuzzy decision making algorithm, whose output (shown in Fig. 9) can be used to select the most plausible track reference points over each row and fit a straight line to those points. From the straight line, the track position and orientation, as well as the track selection fuzzy degree of confidence can be obtained (Portela *et al*, 2000).

The track follower consists of a closed loop fuzzy guidance controller (Marques *et al.*, 1998). The two outputs of the track detector are fuzzified and fed into a rule-based table resulting from the controller discretization. The controller output is the set point for the steering angle control loop, a PID position controller, which guarantees the required steering accuracy. The guidance control loop sampling time is several orders of magnitude slower than the steering angle control loop. Fuzzy rules were used for two reasons: past experience had shown that a linear PD controller is difficult to tune and its performance is not fully satisfactory; on the other hand, the design of a non-linear controller for non-holonomic vehicles is a considerably complex task (especially for tricycle-like vehicles) whose practical results may not justify the time spent with this particular subsystem. The fuzzy controller was relatively easy to tune, based on geometrical considerations and enumeration of all possible vehicle-track relative situations.

The driving speed is set from the recognition confidence level of the track parameters *a* and *o*, which is also based on fuzzy processing (Wang, 1994).

This solution for the guidance system proved to be much more robust than the one used in (Lima *et al.* 1998), which was very sensible to the environment light and needed a time-consuming number of sensible threshold calibrations made along the whole track.

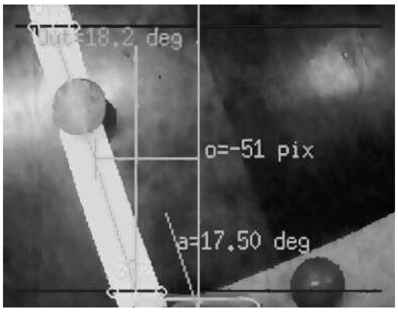

Fig. 9. Track Detection: *a* is the angle representing the vehicle orientation with respect to the track; *o* is the distance from the vehicle to the track reference point.

State transitions can be smoothed from the information provided by the look-ahead camera, that searches continuously for track interruptions, and signals them, via TCP/IP sockets, to the supervisory system. In this way, the vehicle may slow down when an interruption is approaching and learn the track resuming point after an interruption in advance, avoiding the need to stop at an interruption to look for the resuming point.

7. RESULTS

Results of the track detector navigation subsystem are shown in Fig. 10. The figure presents a sample image (with several false tracks), the plots of the brightness along two vertical and three horizontal image rows, the corresponding 1-D derivatives, the classification matrices (in a 0-10 scale) of nine max-min pair combinations, for the three fuzzy features referred in the previous section, and the final confidence level on the detection of a track for each row. The detection of a track in the horizontal rows is made with a clearly higher confidence level, as expected, despite the false tracks and other image noise. The horizontal bottom sample achieves the top confidence level, especially due to a better contrasted image and track width closer to the nominal value.

8. CONCLUSIONS

This paper presented the design and implementation of a small autonomous mobile platform, with an open control architecture that integrates the different functional and hardware modules. The platform was developed to be used to meet the constraints of the 1999 edition of the "*Festival International des Sciences et Technologies*" and as a testbed for research and development on mobile robotics.

The main feature displayed by IQ99 was its ability to correctly handle the coordinated execution of several subtasks. The robot correctly followed an optical track, regained the track after interruptions, left the track and knocked down a ball from the top of a post, came back to the track and did the rest of the way to the arrival without faults. Moreover, the robot collected and discriminated all the French billiard balls correctly. The use of fuzzy decision making to identify the track proved to be a very robust solution.

The robot achieved the second place in the competition and obtained the first prize for the best robot in its class that was delivered by the jury of the competition.

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REFERENCES

Aparício P., Ferreira J., Raposo P., Lima P., (1998), "BARBANETA – A Modular Autonomous Vehicle*", Proceedings of IFAC Intelligent Autonomous Vehicles*, Madrid, Spain

Astrom, Karl J., Wittenmark, B. (1996), "Computer Controlled Systems : Theory and Design", Prentice-Hall, London

Jain, Anil K. (1989), *Fundamentals of Digital Image Processing*, Prentice-Hall, London

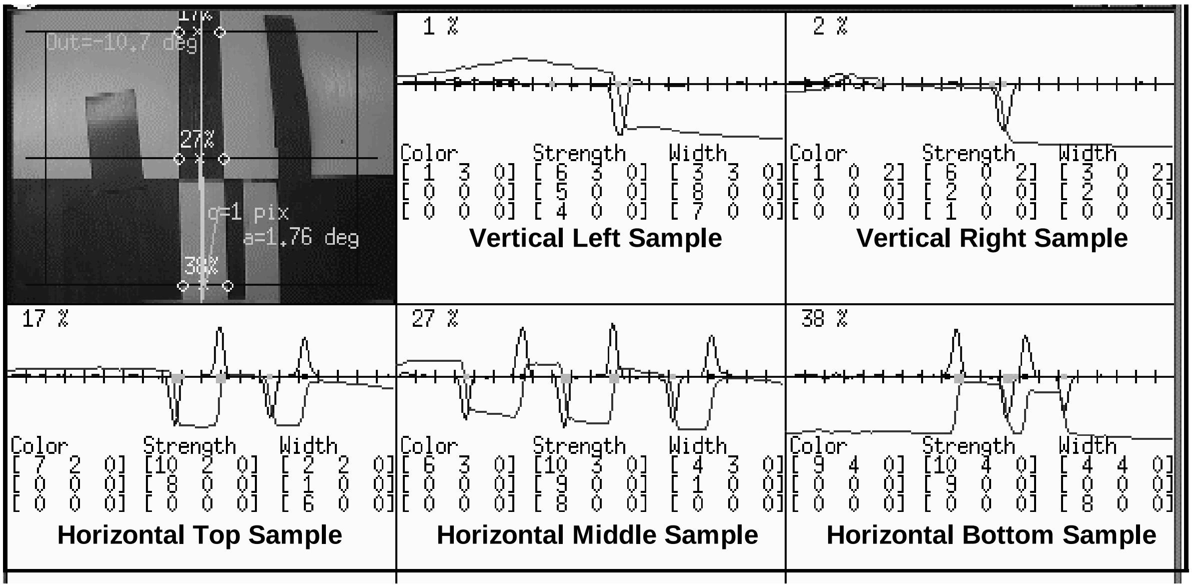
Lima, P.; Silva, P., Santos, J., Cardeira, C. (1998)*;* "Centaur: A Vision-Based Autonomous Mobile Robot*" in Proceedings of EUREL'98 European Advanced Robotics System Development: Mobile Robotics*, Leiria, Portugal, September 14-16.

Marques, C., Portela, N., Lima, P. (1998), *IQ1 – Robot Competidor*, ISR Internal Report RT-406-98, Portugal.

Portela, N., Marques, C., Lima, P. (2000), "Optical Track Detection for Mobile Robots Based on Real Time Fuzzy Decision-Making", *in Proc. of IEEE Internat. Symposium on Intelligent Control (ISIC'2000)*, Patras, Greece.

Stevens, W. R.(1990), *Unix Network Programming*, Prentice-Hall, New Jersey.

Wang, L.-X., (1994). *Adaptive Fuzzy Systems and Control: Design and Stability Analysis*, Prentice-Hall, New Jersey.



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Color        Strength     Width
[ 1  3  0]  [ 6  3  0]  [ 3  3  0]
[ 0  0  0]  [ 5  0  0]  [ 8  0  0]
[ 0  0  0]  [ 4  0  0]  [ 7  0  0]
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Color        Strength     Width
[ 1  0  2]  [ 6  0  2]  [ 3  0  2]
[ 0  0  0]  [ 2  0  0]  [ 2  0  0]
[ 0  0  0]  [ 1  0  0]  [ 0  0  0]
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Color        Strength     Width
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[ 0  0  0]  [ 8  0  0]  [ 1  0  0]
[ 0  0  0]  [ 0  0  0]  [ 6  0  0]
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[ 6  3  0]  [10  3  0]  [ 4  3  0]
[ 0  0  0]  [ 9  0  0]  [ 1  0  0]
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[ 0  0  0]  [ 0  0  0]  [ 8  0  0]
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Fig. 10. Results of the track detector application to several rows of a sample image.