

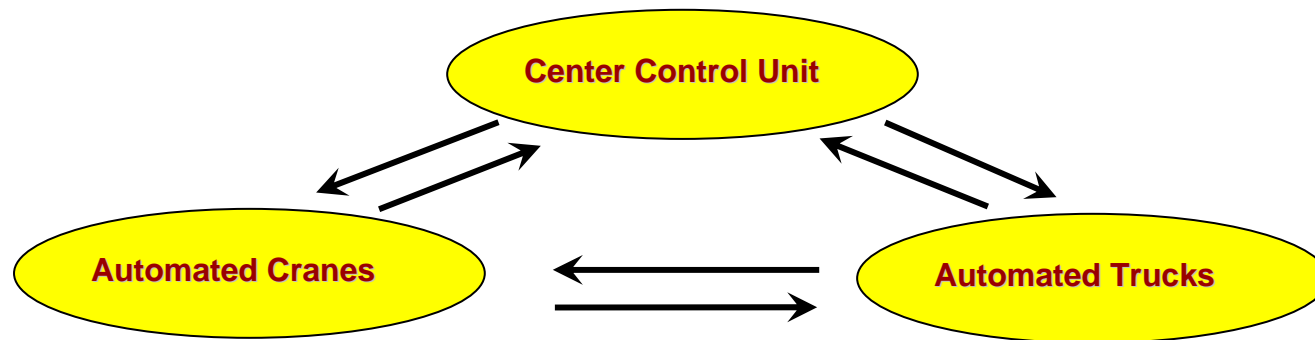
3D Tree-Structured Object Tracking for Autonomous Vehicles

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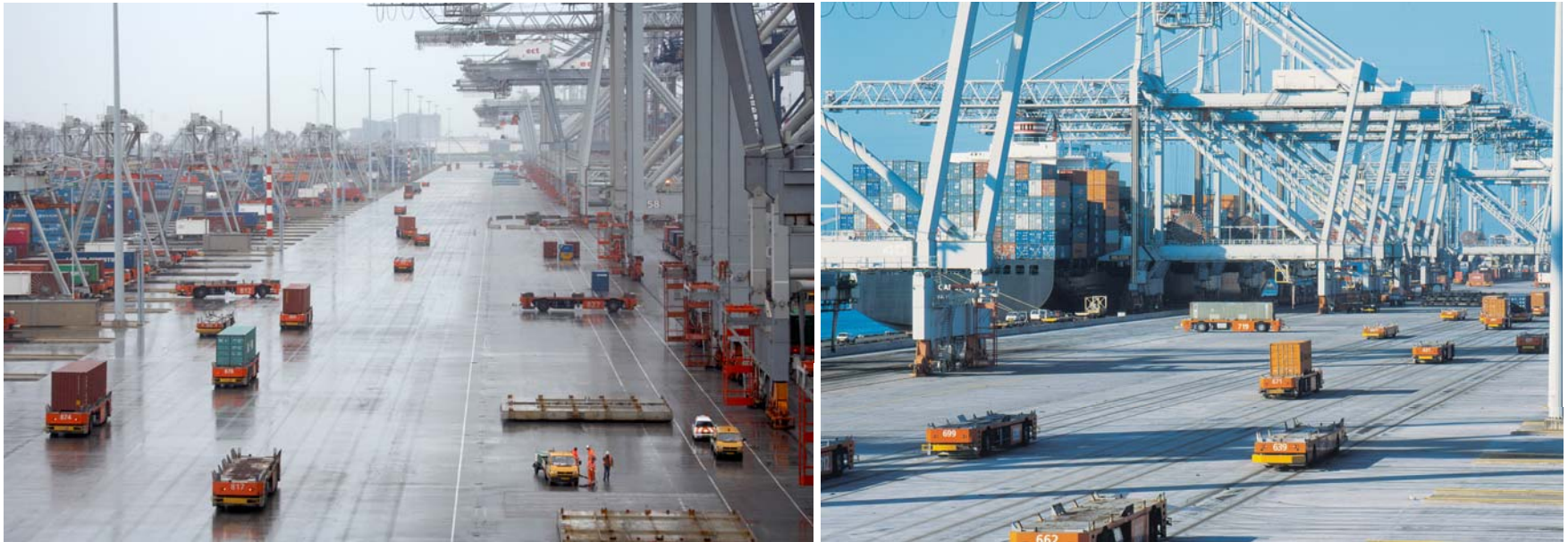
Port of The Future

- Need fast processing time for increasing volume of cargo
- Energy efficient facilities are needed
- Safe worksite is important to both human and cargo
- Vehicle with a decision making (not remote controlled)



What it will have → **Automated Terminal**

An Existing Automated Port



<http://www.gottwald.com/>

European Container Terminal (ECT)

Rotterdam, Netherland

Automated Stacking Cranes, Trucks, Control Center

Autonomous Vehicles used in the Automated Port



<http://www.gottwald.com/>

An Automated Guided Vehicle at ECT Rotterdam

Objective : The vehicle follows a guide line

Experimental Autonomous Vehicles



- Objective - find safe region to drive 170 miles across the desert in 10 hour
- Use camera vision to extend sensor range
- Laser and camera are key devices to detect obstacles

<http://cs.stanford.edu/group/roadrunner//old/index.html>

Stanford Stanley
A Winner of DARPA Grand Challenge in 2005

Another Autonomous Vehicle



- **Objective – drive with limited traffic conditions on city streets**
- **Use cameras, radar, laser**
- **Array of laser is a key device to detect obstacles**

<http://www.tartanracing.org/>

**CMU Tartan
A Winner of DARPA Urban Challenge in 2007**

Autonomous Vehicle Constructed by A. Parker and Team



<http://www.teamtormenta.com/>

Team Tormenta

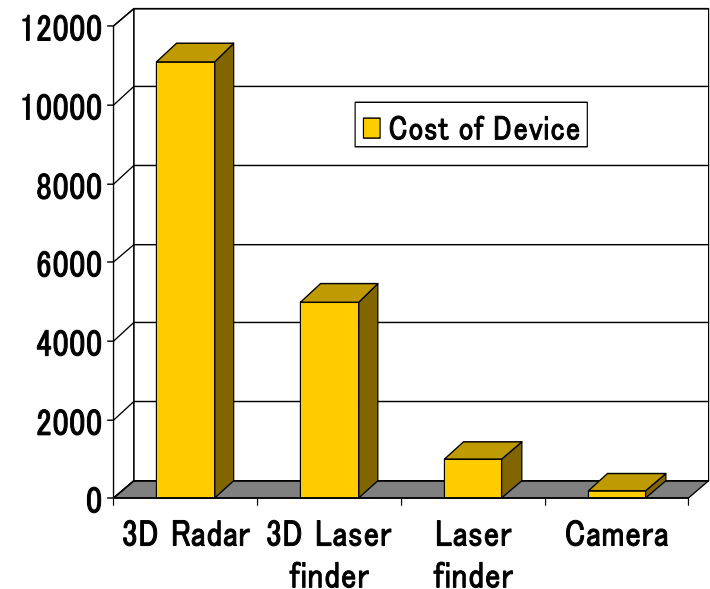
A NQE Entry of DARPA Grand Challenge in 2005

Stereo camera vision was successful for obstacle avoidance

Our Problem

• Vehicle Guidance System

- Many useful sensors (GPS, Radar, Laser rangefinder, camera, stereo camera)
- Must detect, avoid moving obstacles
- Must detect obstacles while moving
- Need 3-D information (Depth)
- Need to predict obstacle trajectories to avoid collisions



Issues with Possible Technologies

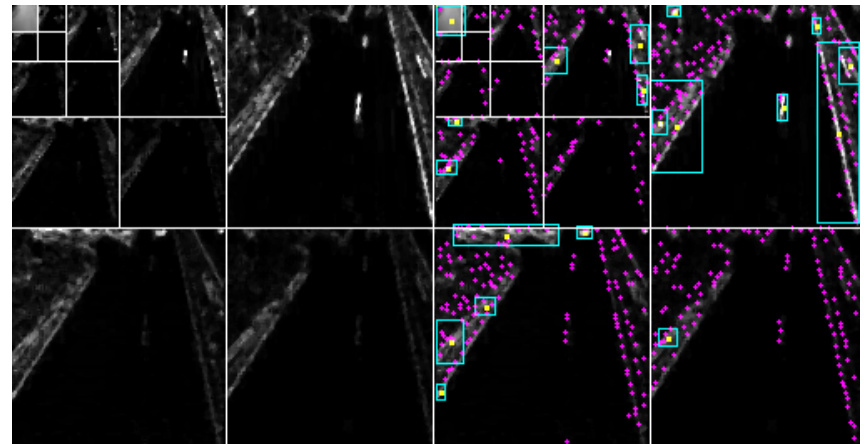
- Cost of radar and laser rangefinders prohibitive
- Stereo cameras must be recalibrated frequently
- Single camera with trajectory estimation
 - Need a higher level image understanding technique
 - Accuracy and reliability are key concerns
 - Can be combined with other sensors (GPS, laser, radar)

Our Single-Camera Approach

- Wavelet-based Processing
 - Multi-resolution processing (results in images with different resolution information)
 - Spatial Domain processing (location information is preserved)
- 3-dimensional Object Detection
 - Spatial Object Detection (Features) → Key-Point Extraction
 - Temporal Object Detection (Motion) → Optical Flow
- Object Tracking using a Kalman Filter
 - Predict next position based on previous noisy measurements
 - Tracks objects that are detected by 3D object detection
 - Finds trajectories that might be unsafe to us in our tree-structure

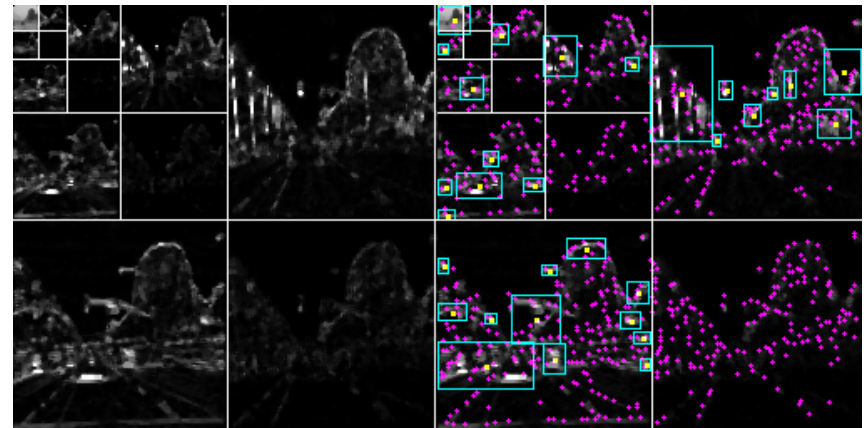
Results

- Object tracking with stationary camera
 - Wavelet-domain key-point extraction for detection of 2D features
 - Temporal motion detection for estimation of object's motion
 - Stationary key-points are removed (safe objects)
 - Traffic monitoring

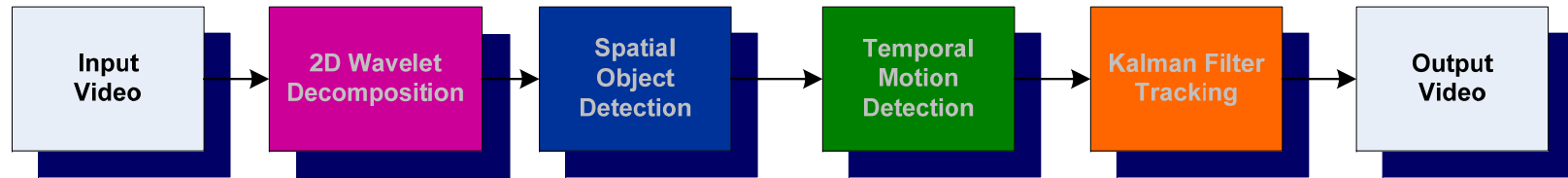


Results

- Object tracking with moving camera
 - Optical flow fails to detect objects because every pixel is in motion
 - Need to separate potential obstacles from unimportant pixel motion
 - Use key-point extraction along with optical flow to only detect important objects



Block Diagram of Object Tracking Algorithm



- **2D Wavelet Transform** → Different freq. responses with location information
- **Spatial Object Detection** → Key-point extraction based on finding maxima points in wavelet domain
- **Temporal Motion Detection** → Optical flow using *Horn-Schunck* method
- **Kalman Filter Tracking** → Predict, track moving objects

Conclusion

- ***The wavelet domain tree structured object tracking approach is a cost and performance effective solution***
- ***The algorithm consists of wavelet transform, spatial feature extraction, temporal motion detection and Kalman filter tracking.***
- ***Using a tree data structure, temporal behavior of objects can be extracted.***
- ***Challenges remaining → shadows, rainy, foggy condition and with dynamic vehicles.***
- ***Higher-level sophisticated reasoning is required → On-line learning with dynamic conditions***