Embedded 3D Stereo Vision: How it Works, How to Implement It, and How to Use It

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Contributors for algorithms, optimization, and prototypes

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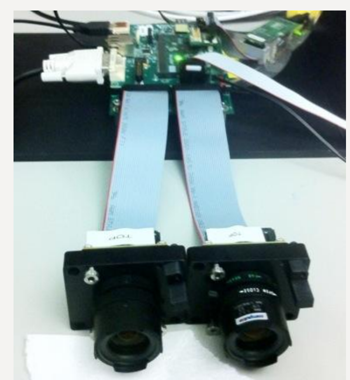
TI Design Network partners:

- Leopard Imaging
- Critical Link
- D3 Engineering



Understanding 3D: Sensors, algorithms, applications

Stereo Vision

Structured Light

Time-of-Flight

LIDAR

Radar

Application Requirements
- indoor
- outdoor
- static/moving
- low-light

3D point cloud
- range
- resolution
- frame rate
- accuracy
- density
- baseline

Algorithms
- detection
- tracking
- kinematics
- classification
- segmentation

Automotive
- obstacle detection
- backover warning
- collision avoidance

Video Analytics
- robust analytics
- occupancy sensor

Human-Device Interaction
- gesture
- multi-touch
- 3D interfaces
- games

The requirements for 3D vary significantly from one application to another.

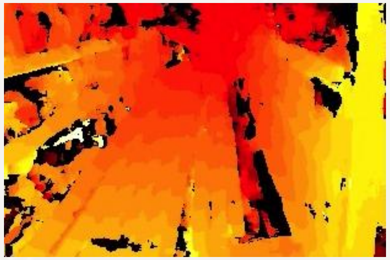
Stereo vision uses a pair of images to estimate 3D depth

left image

+

right image

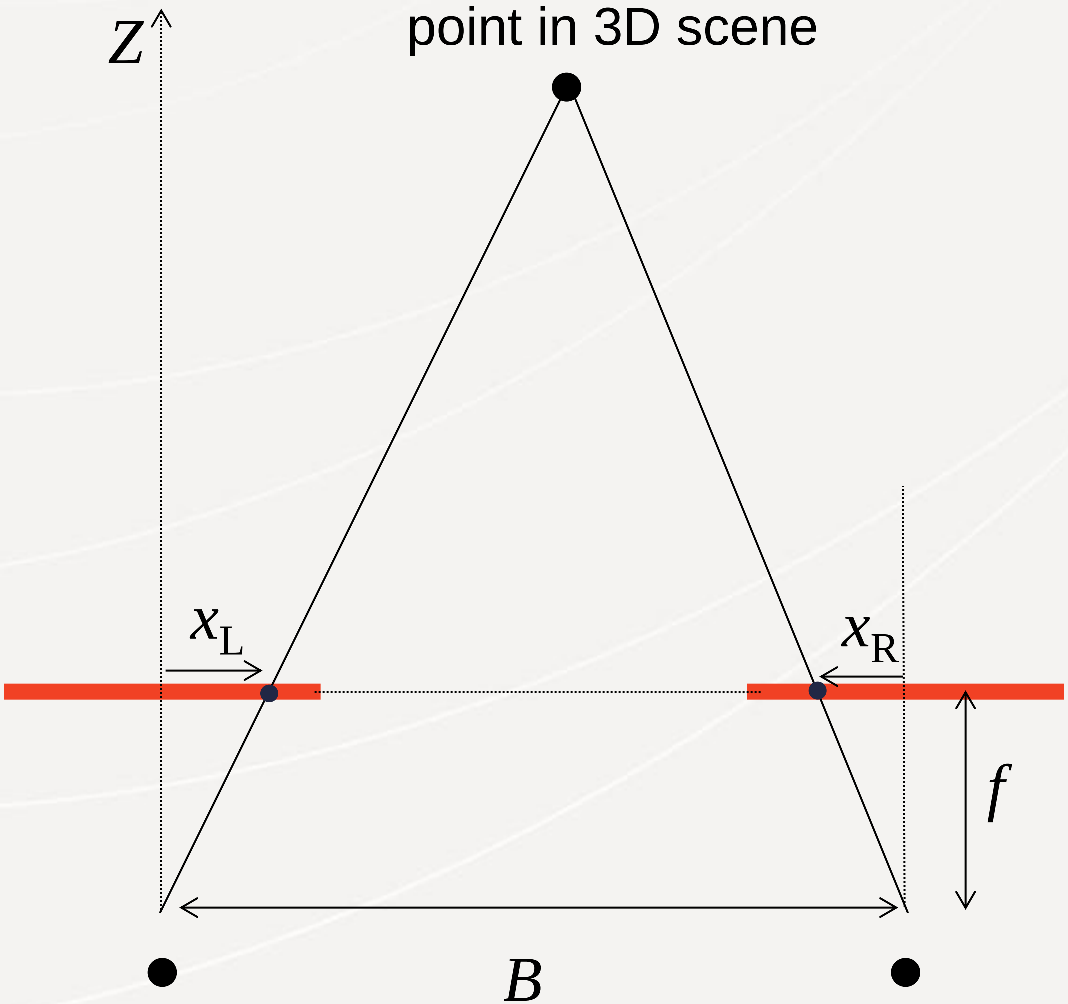
stereo algorithm



disparity image (inverse depth)

- Passive depth sensing –does not require flooding the scene with light
  - Exploits the ambient illumination of the scene: low power
  - No interference problem between stereo cameras
  - Can be made to work in the dark with external light source
- Works by geometric “triangulation”
  - For better depth resolution, use higher resolution sensor or larger camera separation
  - When the scene is homogenous/textureless (e.g., blank wall), stereo algorithms may not be able to establish correspondence between left/right images

From disparity to depth



disparity

coordinates of the corresponding point

$$d = x_L - x_R$$

Fundamental relation of stereo:

baseline

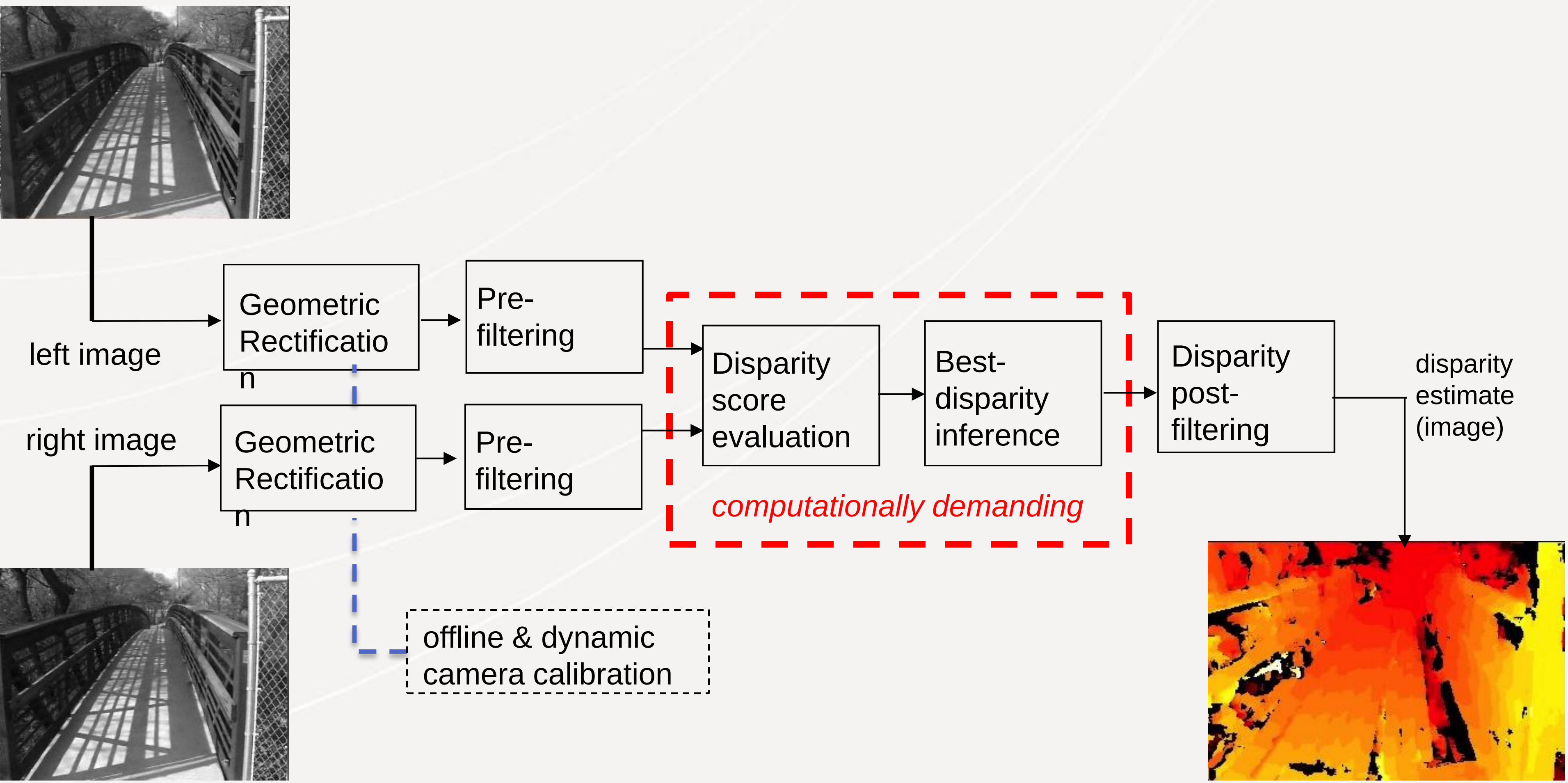
focal length

$$Z = \frac{Bf}{d}$$

depth

disparity

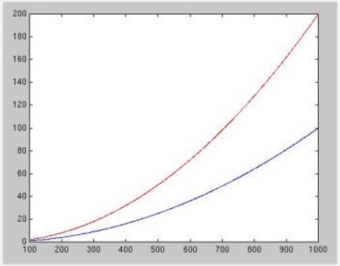
Typical stereo vision processing pipeline



Challenge: depth resolution

- What is the sensitivity of depth estimates to errors in disparity?

$$Z = \frac{Bf}{d} \quad \Rightarrow \quad \left|\frac{\partial Z}{\partial d}\right| = \frac{Z^2}{Bf}$$



- Depth resolution decreases quadratically
  - Severe limitation on the applicability
  - Motivates sub-pixel disparity methods
- Depth resolution improves with baseline & focal length
  - However, matching gets more difficult
  - Synchronization among image sensors becomes challenging
  - Drives requirements for higher resolution sensors

TI Stereo Module (TISMO) SW prototype

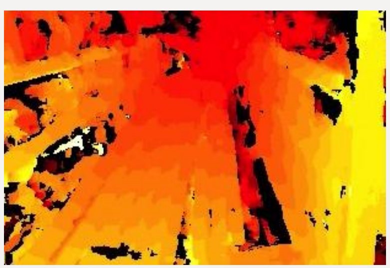
- DSP-optimized SW solution for computing disparities.
- Adapted for embedded constraints, while satisfying use-case requirements.
- Our guiding principle is application-level enablement; we build and test out prototypes to gauge the suitability of our depth images.

left image

+

right image

stereo algorithm

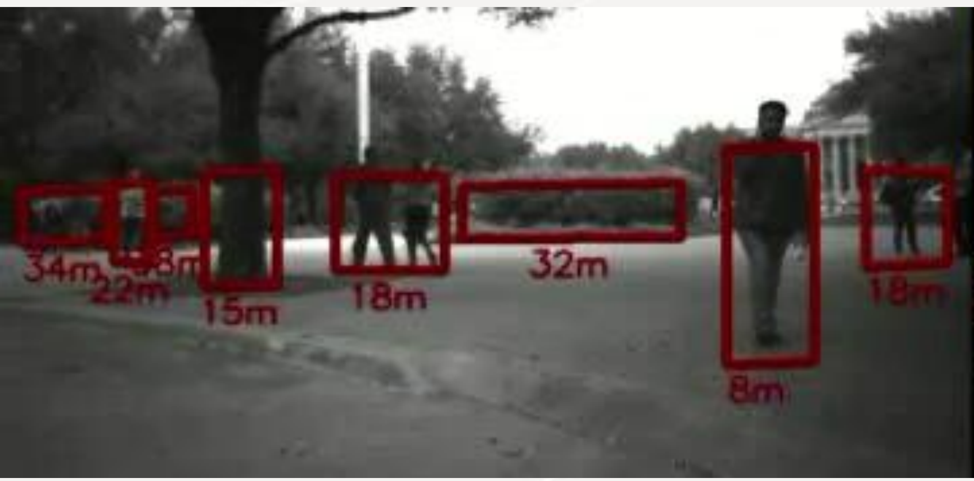


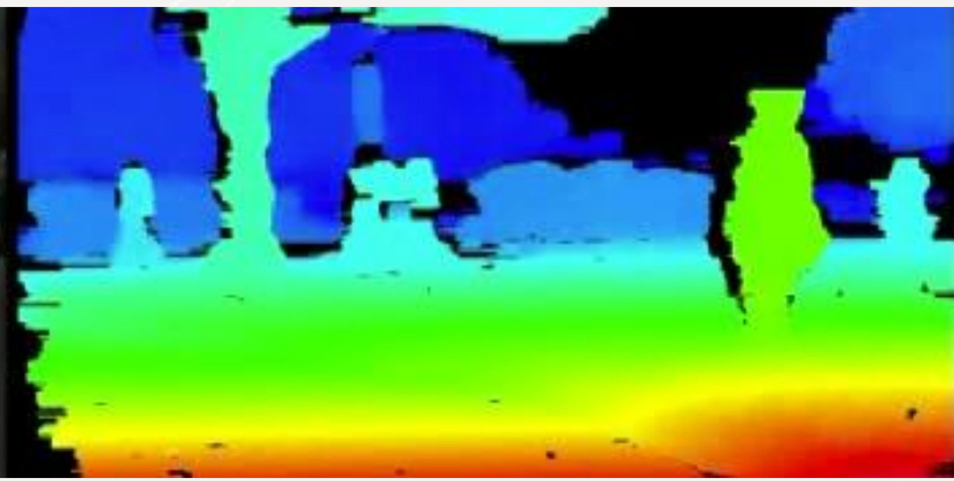
disparity image
(inverse depth)

Prototype: obstacle detection for automotive safety

Obstacles detected via stereo depth

Disparity output





Prototype: motion detection for video security

Input frame

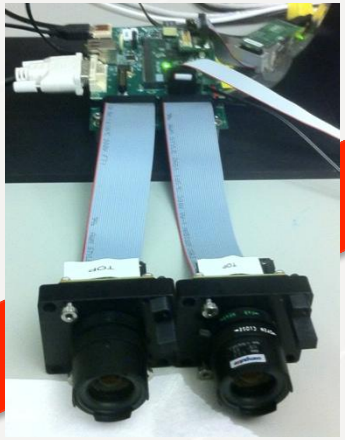
Disparity output

Motion detections

We demonstrate four different embedded stereo vision prototypes highlight the scalability of our DSP solutions

embedded VISION SUMMIT

OMAP™ 4 processor



OMAP™ L138 DSP+ ARM processor

DM8127 DaVinci™ video processor

Keystone™ C6678 processor

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Conclusions

- Stereo vision is a well-studied & understood modality for 3D depth sensing
- High-volume stereo products on the way
- We have implemented embedded stereo vision on a variety of SoCs with the C6x DSP core: OMAP4, OMAP-L138, DM6437, DM8127, C6678
- We have shown application prototypes in automotive safety and video security domains using stereo depth
- Three key messages:
  - Advantage: low-power, low-cost
  - Challenge: computationally demanding; algorithms still evolving
  - With the right programmable processor and careful design trade-offs, stereo vision can be implemented with cost & power consumption suitable for embedded systems.

Resources for Further Investigation

- Technical literature
  - IEEE Journals & Conferences
  - IEEE Embedded (Computer) Vision Workshop (2005–present)
- For (academic) benchmarks & datasets, see the Middlebury stereo page
  - http://vision.middlebury.edu/stereo
- Stop by to see our live demonstrations!
- Watch a video of our demos: http://bit.ly/12dTmL9