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A High Resolution 3D Tire and Footprint Impression Acquisition Device for Forensics Applications

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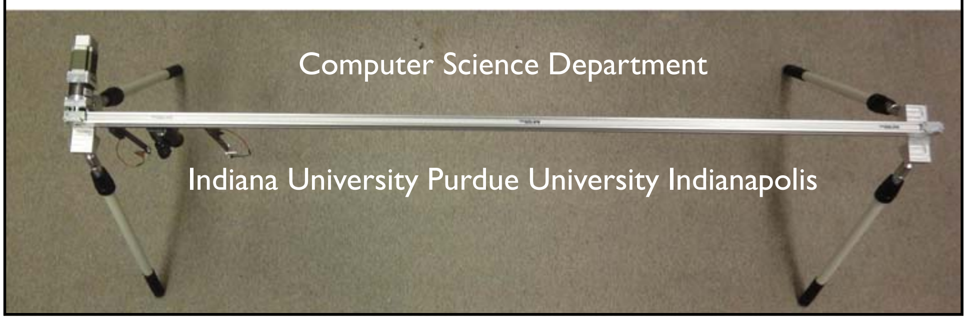


Background in forensic investigation

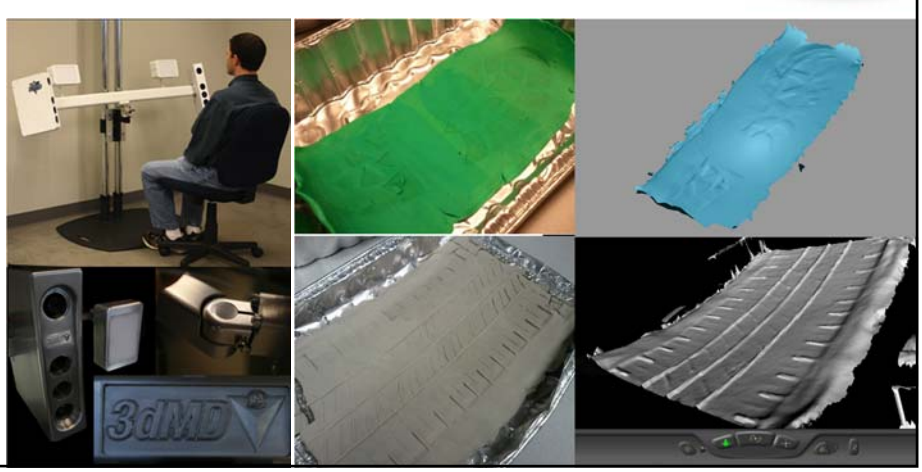
- In crime scene investigations it is necessary to capture images of impression evidence such as tire track or shoe impressions.
- Currently, such evidence is captured by taking two-dimensional (2D) color photographs or making a physical cast of the impression in order to capture the three-dimensional (3D) structure of the information
- The process is time consuming and distructive

Objectives of this work

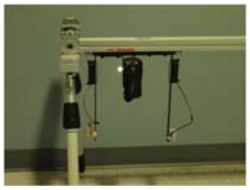
- Scan 3D depth of impression of tires and shoes in crime scenes to enhance color images, when the texture and lighting can not reveal the impression
- Obtain complete and high resolution 3D images in a large span for tire impression
- Portable design and easy to use for outdoor measuring
- Scan real shoes and tires

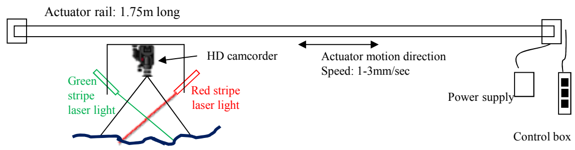
Available technology for impression

- Small field of view and high resolution
- Non-Portable, heavy, fixed systems for indoor use



Basic design of hardware system





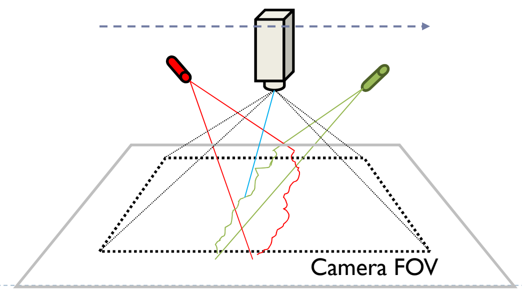
- Linear actuator with a laser-and-camera set moving along a rail
  - Actuator moves precisely at a fine interval (lowest speed 1.3138 mm/s)
  - One touch button to drive
- Two laser planes to eliminate blind spots for complete depth map
  - Red and green lasers are fused in their measured data for all surfaces
- HD video to take dense data and thus high resolution
  - Video recorded in 30frame/sec to memory card for processing in PC
  - Possible to zoom further for higher resolution

Merits of our system

- On-site calibration to avoid the invalidation of a pre-calibrated system in transportation and setup
- Light weight for portable use: 10kg include rail and motor
- Large span for tire impression:1.8m no need of stitching
- Obtain depth and texture map simultaneously
- High resolution: (X,Y, Z) = (0.2369, 0.0438, 0.2) mm, could be higher using zoom in and sub-pixel techniques

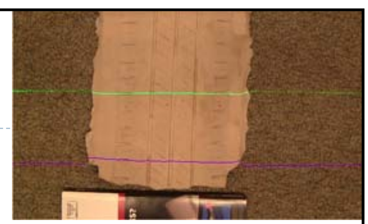
Principle to acquire depth

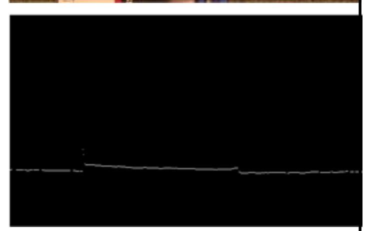
- Calibration of camera-laser relation with an L-type object
- Detection of laser stripes in video frames
- Estimation of 3D position of laser points in the camera-laser coordinate system
- Construction of entire depth and texture map in the rail coordinate system



Laser line extraction

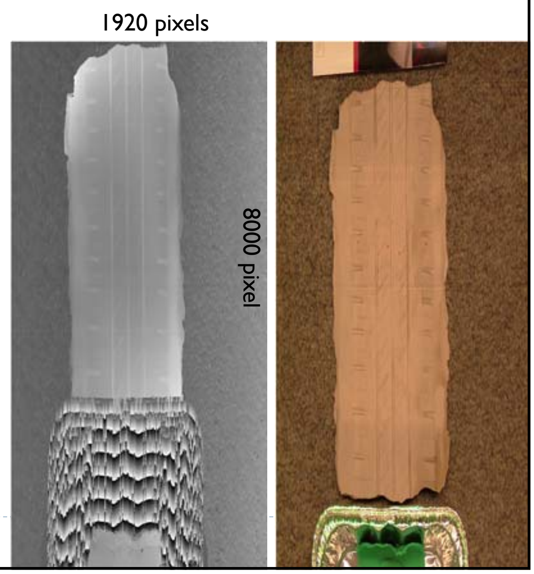
- Find laser peaks vertically in R and G channels by using HSV color
- Detect edges that bound the peak
- Refine edge points at sub-pixel level
- Find the middle point of two edges vertically as the precise laser position





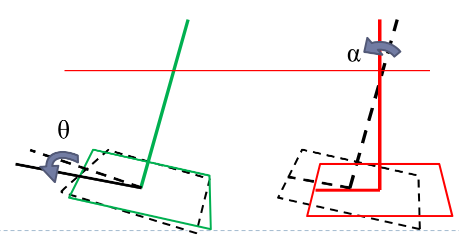
Disparity map and texture map

- Disparity map
  - The image position of laser point is registered as intensity
  - For all the frames in video sequence, their laser positions are collected along the time axis
- Texture map
  - Color pixels obtained from a particular line in each frame
  - Pixels from all the frames are piled along the time axis



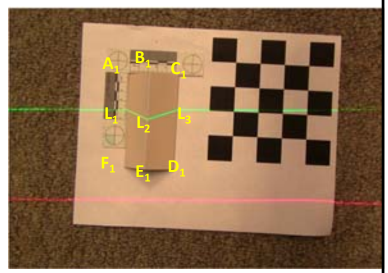
System calibration

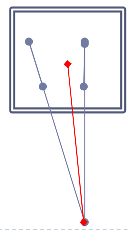
- Ideally the camera should be set orthogonal to the rail, but such an absolute setting is not realistic.
- Under a rough set up of the camera and lasers
  - Rail coordinates system - Motion speed is guaranteed
  - Camera coordinates system – with tilt and roll in rail system
  - Image coordinates system - Focal length, radial distortion, Frame rate at 30fps



Camera pose calibration with respect to rail

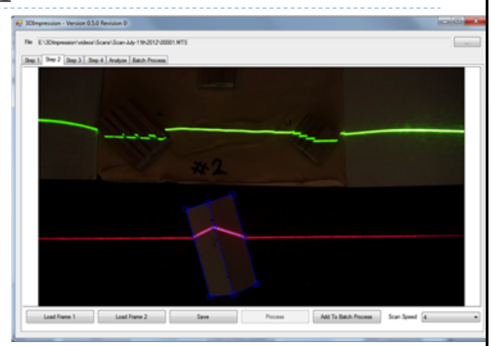
- Place an L-shaped object with known dimensions after the system is set up
- From the recorded video, pick up two images with lasers over the calibration object
- Because of the linear motion along the rail, motion vectors of corner points in the FOV have a vanishing point $p(x_0, y_0)$, at infinite in the ideal orthogonal setting
- Find vanishing point from corners on the calibration object to estimate tilt and roll of camera



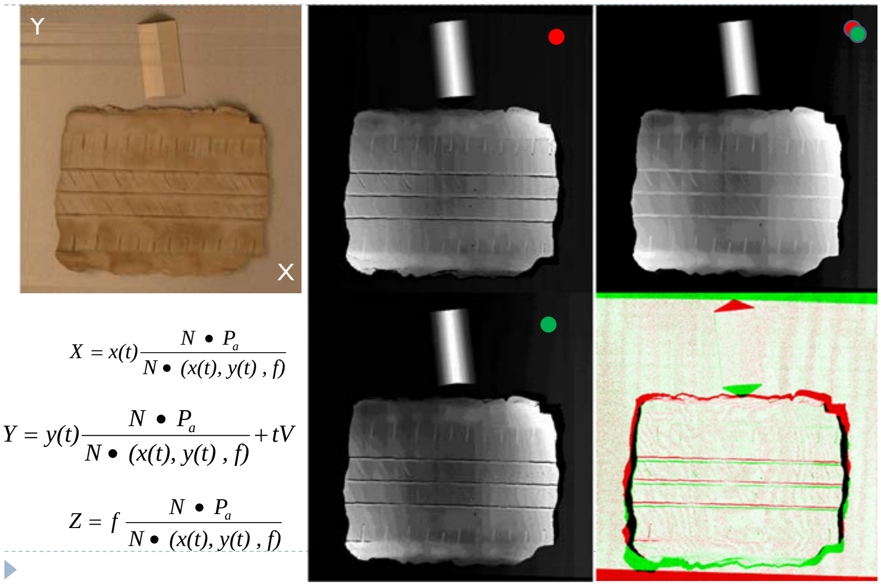


Calibration of laser planes

- Laser on L-shaped object
  - Baseline length between two frames is known from the moving speed and frame number
  - 3D positions of corner points on a calibration object are captured with a developed interface
- Camera-laser relation
  - Find 3D laser lines on the object to estimate the normal of the ray plane



Results from lab scenes



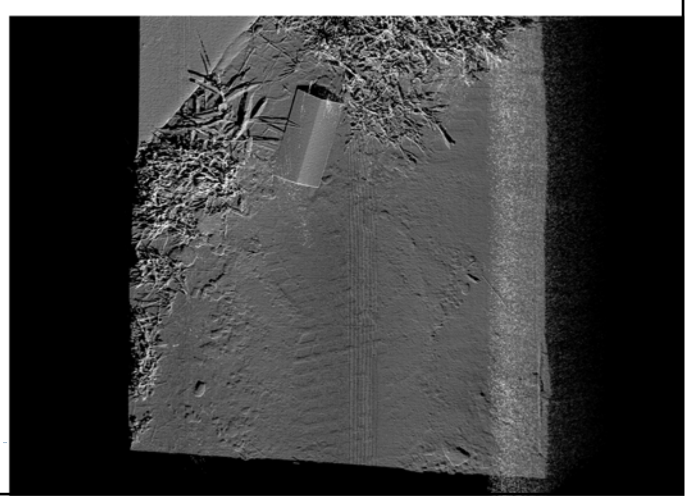
$$X = x(t)\frac{N \bullet P_a}{N \bullet (x(t), y(t), f)}$$

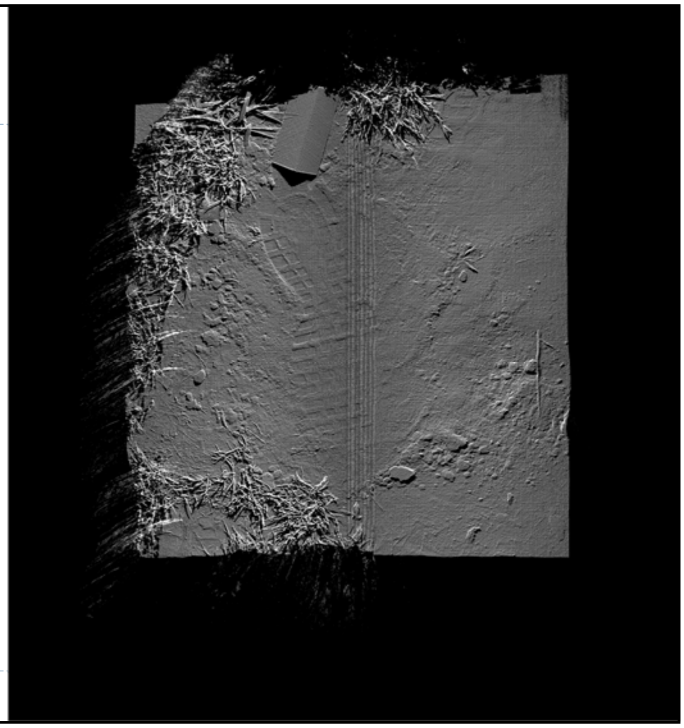
$$Y = y(t)\frac{N \bullet P_a}{N \bullet (x(t), y(t), f)} + tV$$

$$Z = f\frac{N \bullet P_a}{N \bullet (x(t), y(t), f)}$$

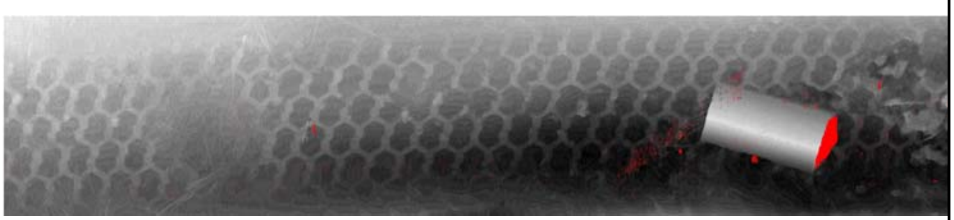
Results of impression on ground

- Image 1920*1080 pixels
- Map 8000*7500 pixels

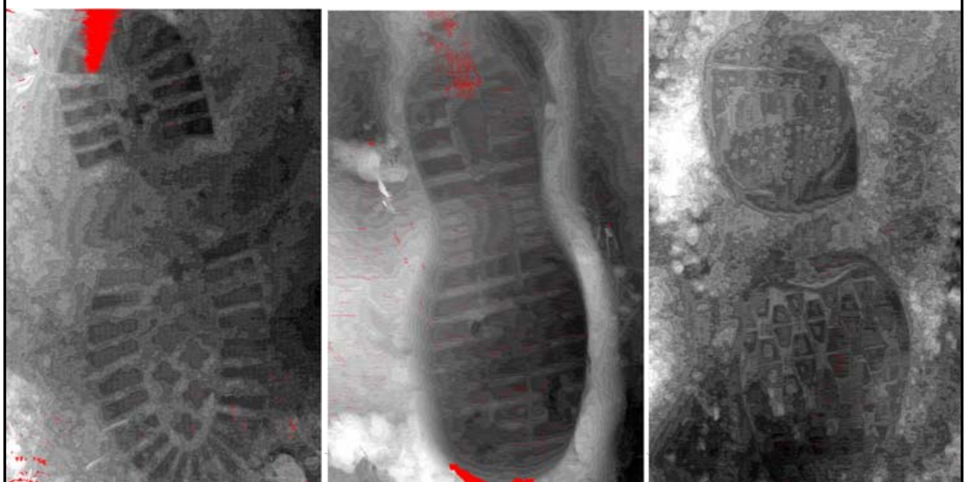




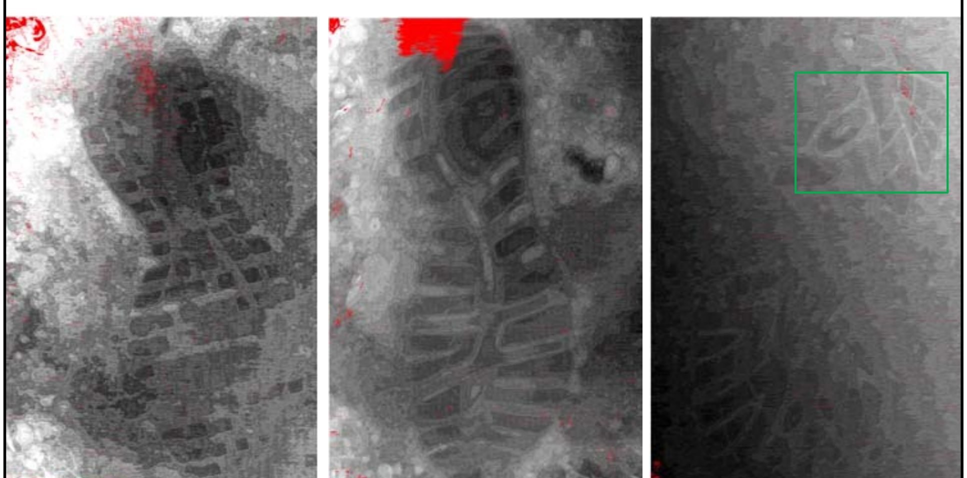
Tire Impression



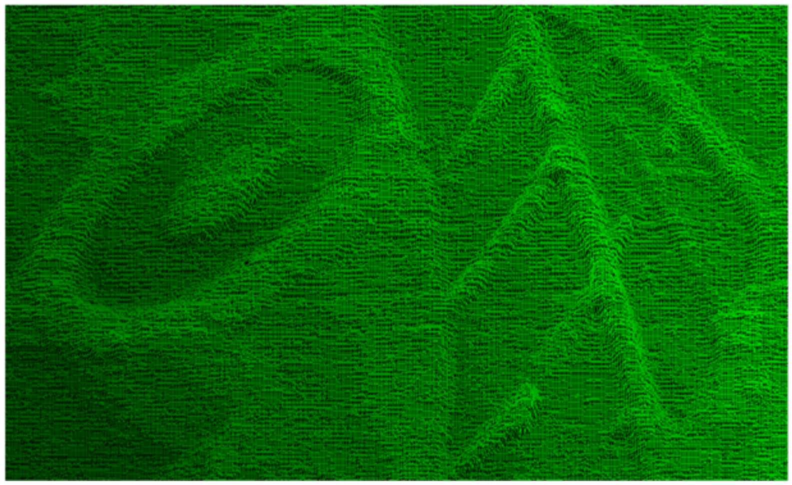
Results on tire impression



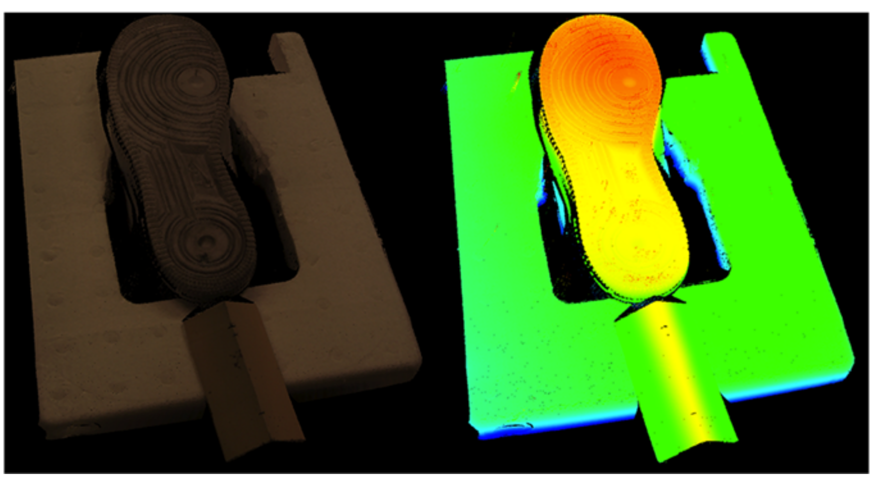
Results on shoe impression



3D mesh of details

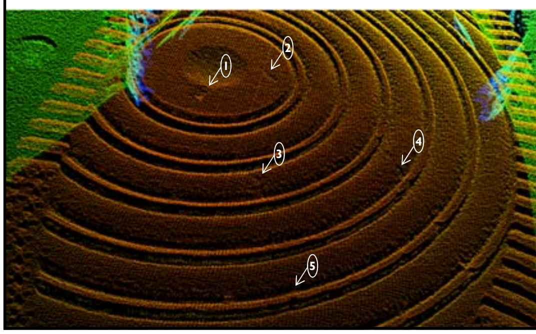


Results on real shoes



Accuracy

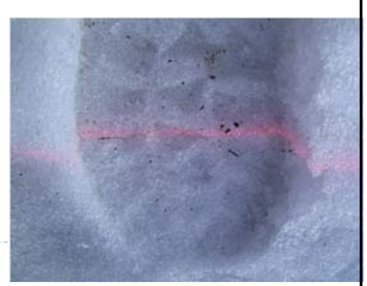
- Horizontal resolution 0.23mm
- Rail resolution 0.043mm
- Depth resolution 0.2mm



Conclusion

- Build an easy-to-use hardware device for 3D impression
- Interface for on-site calibration
- Color image simultaneously for complete surface without occlusion
- Visualize 3D high resolution depth map

- Problems to solve in the future
  - Outdoor lighting – ambient lighting
  - Strong wind
  - Snow scene – scattering of laser light



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