Simultaneous Estimation of Arterial and Venous Oxygen Saturation Using FluxData's FD-1665-MS3

May 18, 2018

One important physiological measurement that a doctor wants to know is the amount of oxygen consumed in different parts of the body. The little instrument that your doctor clips on the end of your finger, a pulse oximeter, can measure SpO_2, peripheral oxygen saturation, by looking at the change in the absorption of a specific wavelength of light due to the pulsing of arterial blood using a photodetector. This measurement is called a PPG, a photoplethysmogram. This measurement is correlated with SaO_2, arterial oxygen saturation. The SpO_2 is related to the amplitude modulation of the pulse signal.

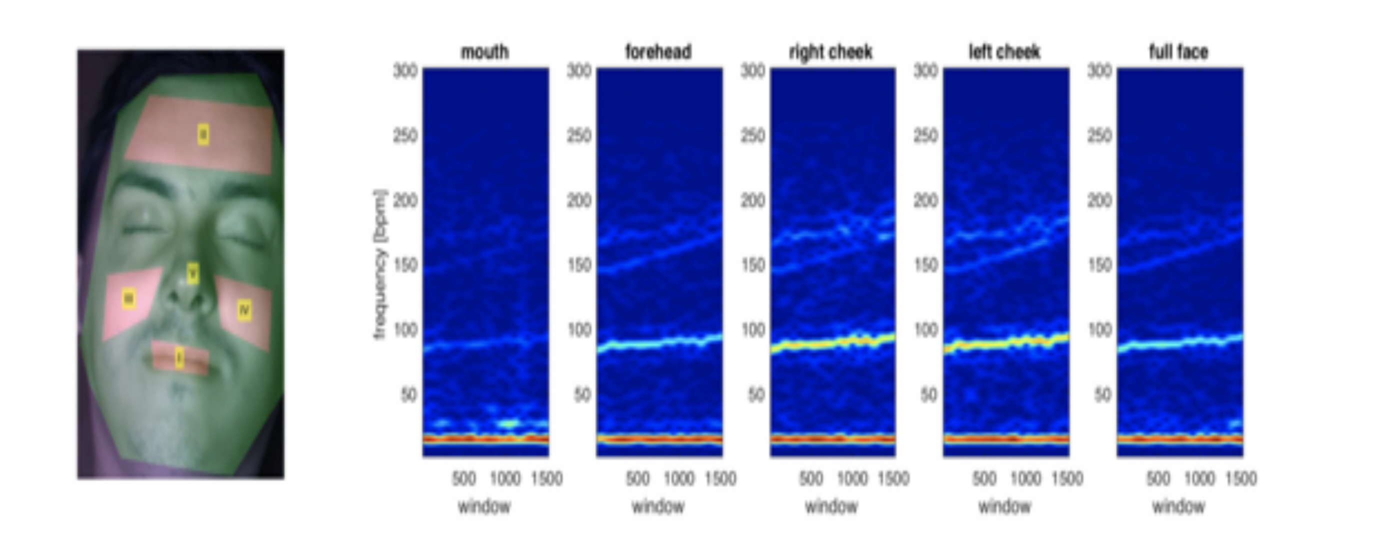
However, to get a better measure of tissue oxygen consumption and blood flow, a measurement of SvO_2, venous blood oxygenation, is also needed. Knowledge of both SpO_2 and SvO_2 would help physicians identify shock or cardiac failure. The usual method of monitoring SvO_2 is to sample blood from a pulmonary catheter. This is invasive and has associated risks, especially in ill or injured patients.

In the paper, Simultaneous Estimation of Arterial and Venous Oxygen Saturation Using a Camera, by Mark van Gastel, Hanbing Liang, Sander Stujik, and Gerard de Haan, from the Department of Electrical Engineering at Eindhoven University of Technology, The Netherlands, the authors investigate making arterial and venous oxygen saturation measurements using FluxData's FD-1665-MS3 multispectral camera. Successful results would mean that doctors could monitor oxygen saturation in a non-invasive way without requiring any instruments to contact the body.

Optical measurement of SvO_2 has been studied before. Because veins have thinner walls and are less elastic than arteries, venous blood flow changes due to respiration and the volume of blood flow can be manipulated by applying pressure to parts of body. Taking advantage of this, one optical method used a strain gauge applied to a finger to modulate the venous flow and thus differentiate it from the arterial flow measured using PPG. Another method is to apply a static pressure to a limb to temporarily stop the venous flow of blood and differentiate SvO_2 and SpO_2 in that way. However, this method can lead to complications.

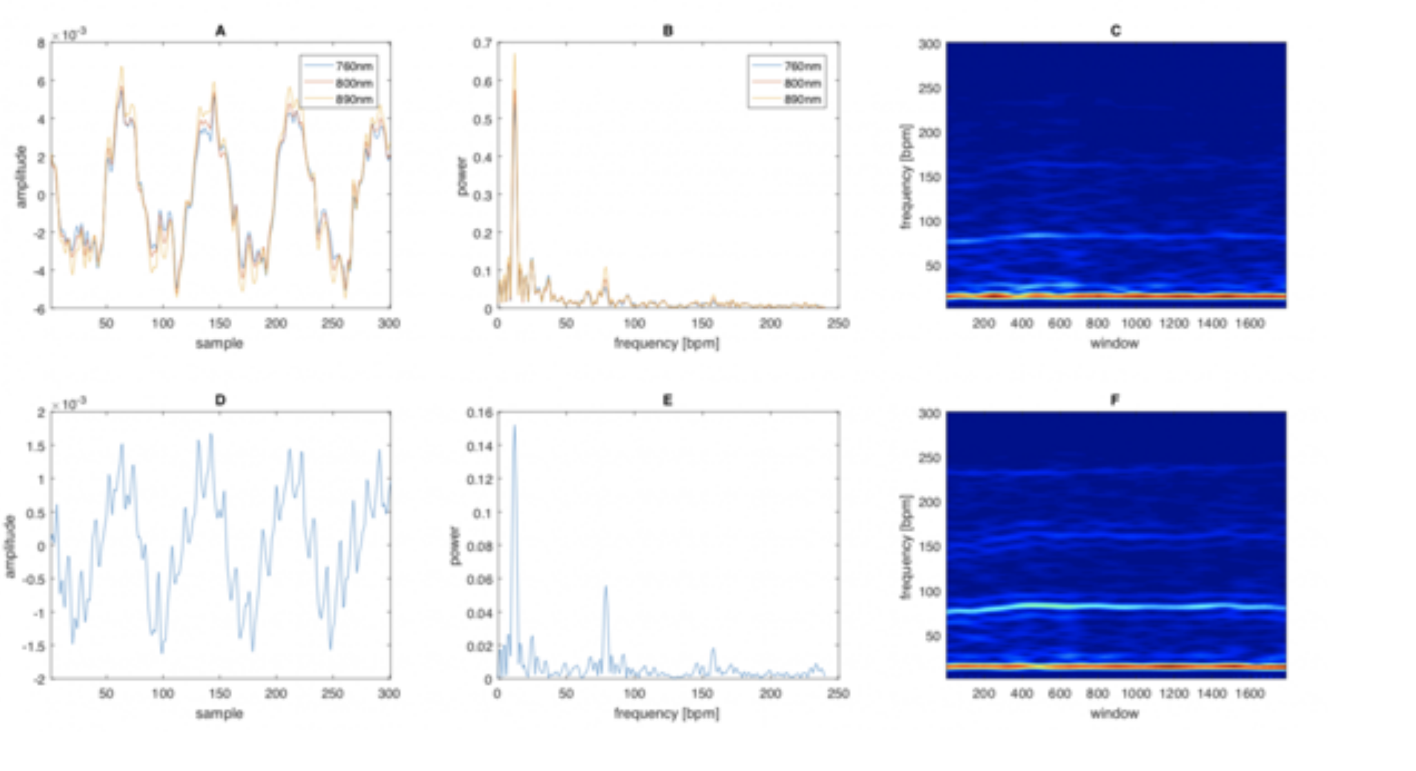
In this study, the FD-1665-MS3 was used to record five regions of interest (ROIs) on healthy subjects faces. The camera imaged the faces at three infrared bands centered at 760, 800, and 890 nm with 25, 25, and 50 nm bandwidths, respectively. The camera was recording at 15 fps. Nine incandescent bulbs, at a distance of 1.5 m from the face, were used to create diffuse homogeneous illumination.

An auditory breathing pattern was used. The subjects synchronized their breathing to this pattern during the 3-minute recording sessions. Because the venous blood flow volume changes with respiration, the experimenters could use this pattern to help differentiate SvO_2 and SpO_2. To help check the validity of the results, a finger pulse oximeter measuring PPG and pulse was used.



(a) Facial ROIs created from landmarks (b) Spectrograms facial ROIs

To reduce noise, the data in each ROI was averaged. The signals in each spectral band were normalized. Using temporal Fourier analysis, the experimenters could look at the amplitude of the signals at differenct frequencies and isolate those that are modulated by the pulse (40-240 bpm) and respiration (10-40 bpm) to calculate the SpO_2 and SvO_2 respectively. Other signal processing steps include the elimination of motion artifacts and the reduction of irrelevant signals.



A) DC-normalized signals from the 3 channels, B) corresponding spectra with peaks at both breathing and pulse rate, C) spectrogram 890nm channel from the full recording, D) signal after projection to eliminate motion artifacts, E) corresponding spectrum after amplitude tuning, F) spectrogram from the full recording.

The results were very promising. The camera-based measurements of the SpO_2 corresponded well with the PPG from the finger pulse oximeter. The SvO_2 measurements were fairly equal for the facial ROIs but showed higher variation than the SpO_2 measurements and were in the range reported in the literature. (There was no empirical comparison for the SvO_2 as there was for the SpO_2.) The ability to measure both arterial and venous oxygenation with this non-contact camera method shows promise because it allows for greater patient comfort, fewer complications, and the ability to measure parts of the body where PPG is not possible. Follow-up studies are needed to further validate (with the invasive SvO_2 gold standard) and refine this technique and to see how this method works with patients undergoing surgery with spontaneous or artificial respiration.

To view the full research article, click here.

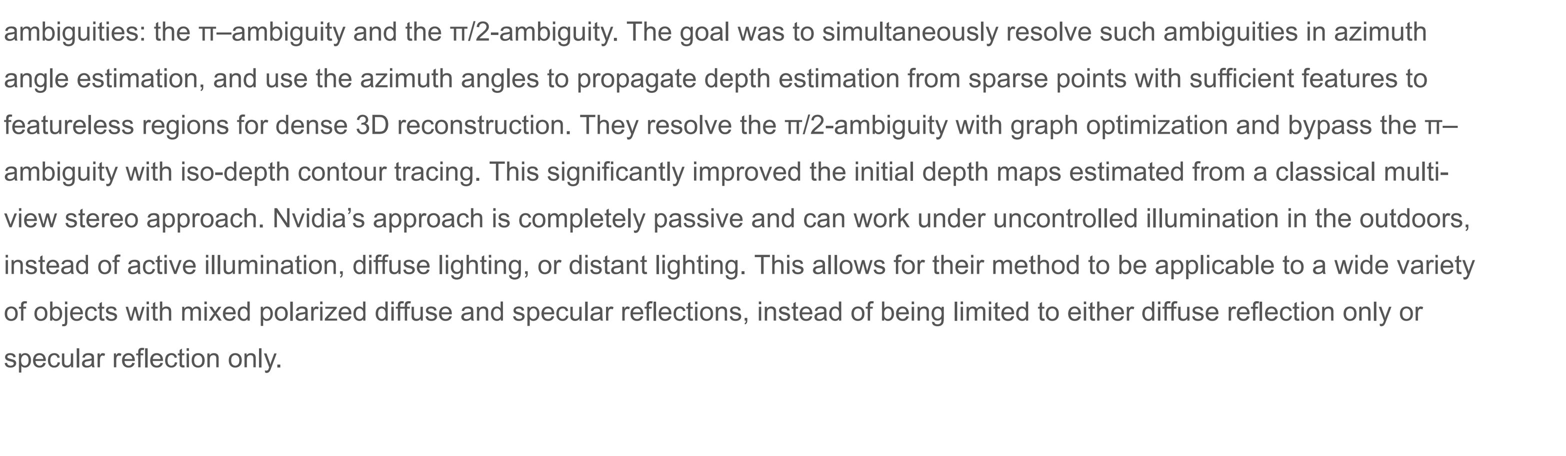
Nvidia Research: Polarimetric Multi-View Stereo

February 14, 2018

Multi-view stereo imagery allows for the reconstruction of dense 3D models from multiple sensors and has been applied to computer graphics, robotics, computer-aided design, and human-computer interactions. It relies solely on finding feature correspondences with epipolar constraints, which has led it to be a system that is viewed as fundamentally flawed when dealing with featureless objects. In their research, Nvidia proposes polarimetric multi-view stereo imaging, which combines per-pixel photometric information from polarization with epipolar constraints from multiple views for 3D reconstruction. In doing so, it reveals surface normal information, which is helpful to propagate depth to featureless regions (something that conventional multi-view stereo cannot do as well). In their research, Nvidia propose a polarization imaging model that can handle real-world objects with mixed polarization, which is possible due to polarimetric multi-view stereo's ability to be applied outdoors in uncontrolled illumination. The researchers prove that there are exactly two types of ambiguities on estimating surface azimuth angles from polarization, which they resolve by completing graph optimization and iso-depth contour tracing. In doing so, they significantly improve the initial depth map estimates, which are later fused together for complete 3D reconstruction. The results of the study showed high-quality 3D reconstruction and overall better performance than conventional multi-view stereo methods, especially on featureless 3D objects (such as ceramic tiles), office rooms with white walls, and highly reflective cars in the outdoors.

Polarization images provide information about surface normal vector fields for a wide range of materials (specular, diffuse, glass, metal, etc.). Polarimetric multi-view stereo is a completely passive approach, and it can be applied to a wide variety of objects in the outdoors with uncontrolled illumination. Using a polarization camera such as the FD-1665P, the scene may be completely characterized using a single temporally-synchronized shot, which avoids motion blur and allows for imaging of dynamic scenes. All prior work assumes either pure diffuse polarization reflection or pure specular polarization reflection, which has made this technology impractical for many real-world objects with mixed polarization reflection.

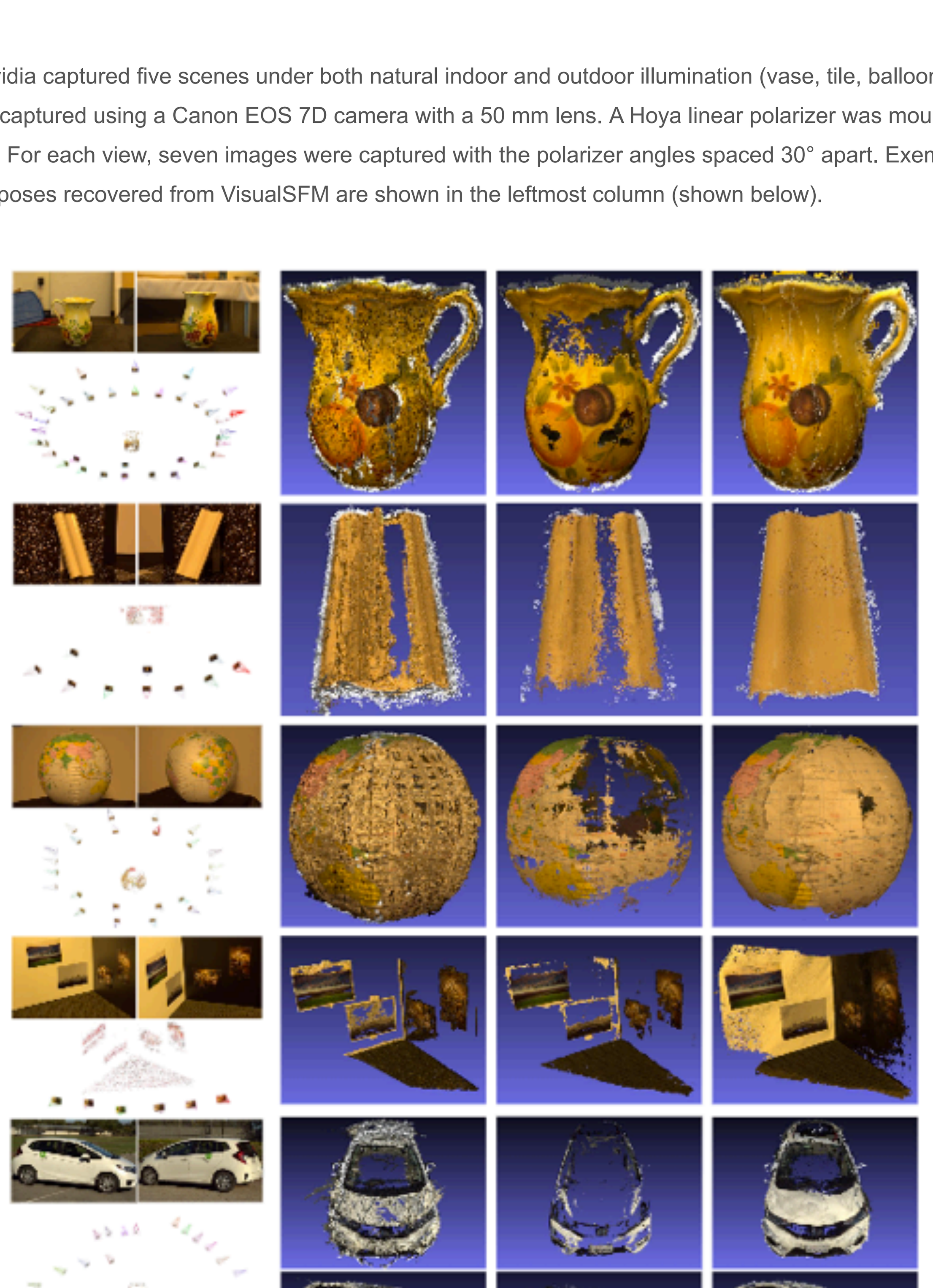
Nvidia's research proves that polarized images can determine the azimuth angles of surface normals with two types of ambiguities: the π–ambiguity and the π/2-ambiguity. The goal was to simultaneously resolve such ambiguities in azimuth angle estimation, and use the azimuth angles to propagate depth estimation from sparse points with sufficient features to featureless regions for dense 3D reconstruction. They resolve the π/2-ambiguity with graph optimization and bypass the π–ambiguity with iso-depth contour tracing. This significantly improved the initial depth maps estimated from a classical multi-view stereo approach. Nvidia's approach is completely passive and can work under uncontrolled illumination in the outdoors, instead of active illumination, diffuse lighting, or distant lighting. This allows for their method to be applicable to a wide variety of objects with mixed polarized diffuse and specular reflections, instead of being limited to either diffuse reflection only or specular reflection only.



Flowchart of proposed polarimetric multi-view algorithm

Shown above is the proposed polarimetric multi-view stereo algorithm. The input consists of polarized images captured at multiple viewpoints, either with polarization cameras or with a linear polarizer rotated at multiple angles. Classical multi-view stereo methods are used to first recover the camera positions as well as the initial 3D shape for well-textured regions. They then compute the phase angle maps for each view from the corresponding polarized images, from which they resolve the ambiguities to estimate azimuth angles to recover depth for featureless regions. Finally, the depth maps from multiple views are fused together to recover the complete 3D shape.

In their study, Nvidia captured five scenes under both natural indoor and outdoor illumination (vase, tile, balloon, corner, car). All images were captured using a Canon EOS 7D camera with a 50 mm lens. A Hoya linear polarizer was mounted in front of the camera lens. For each view, seven images were captured with the polarizer angles spaced 30° apart. Exemplar images and the camera poses recovered from VisualSFM are shown in the leftmost column (shown below).



(a) Sample images (b) MVE [10] (c) Gipuma [11] (d) Ours

Top to bottom rows: Vase, Tile, Balloon, Corner, Car

In the figure shown above, Nvidia shows comparisons against two multi-view stereo methods, MVE and Gipuma, by showing the results after depth fusion for all the methods. For sake of example, in the car image, MVW produced a reasonable reconstruction, but with many outliers. Gipuma could only reconstruct a skeleton of the car. Nvidia's polarimetric multi-view stereo method achieved the most complete and accurate 3D reconstruction of the car, thanks to the estimated phase angle from polarization and depth propagation.

In conclusion, Nvidia successfully presented polarimetric multi-viewed stereo, a completely passive, novel approach for dense 3D reconstruction. Polarimetric multi-view stereo shows its strength especially for featureless regions and non-Lambertian surfaces, where it propagates depth estimated from well-textured regions to featureless regions guided by the azimuth angles estimated from polarized images. Results demonstrated high-quality 3D reconstruction and better performance than standard multi-view stereo methods.

To learn more about polarimetric multi-view stereo, click here.