Computer Vision and Visualization for Implanted Visual Prostheses using Tegra K1

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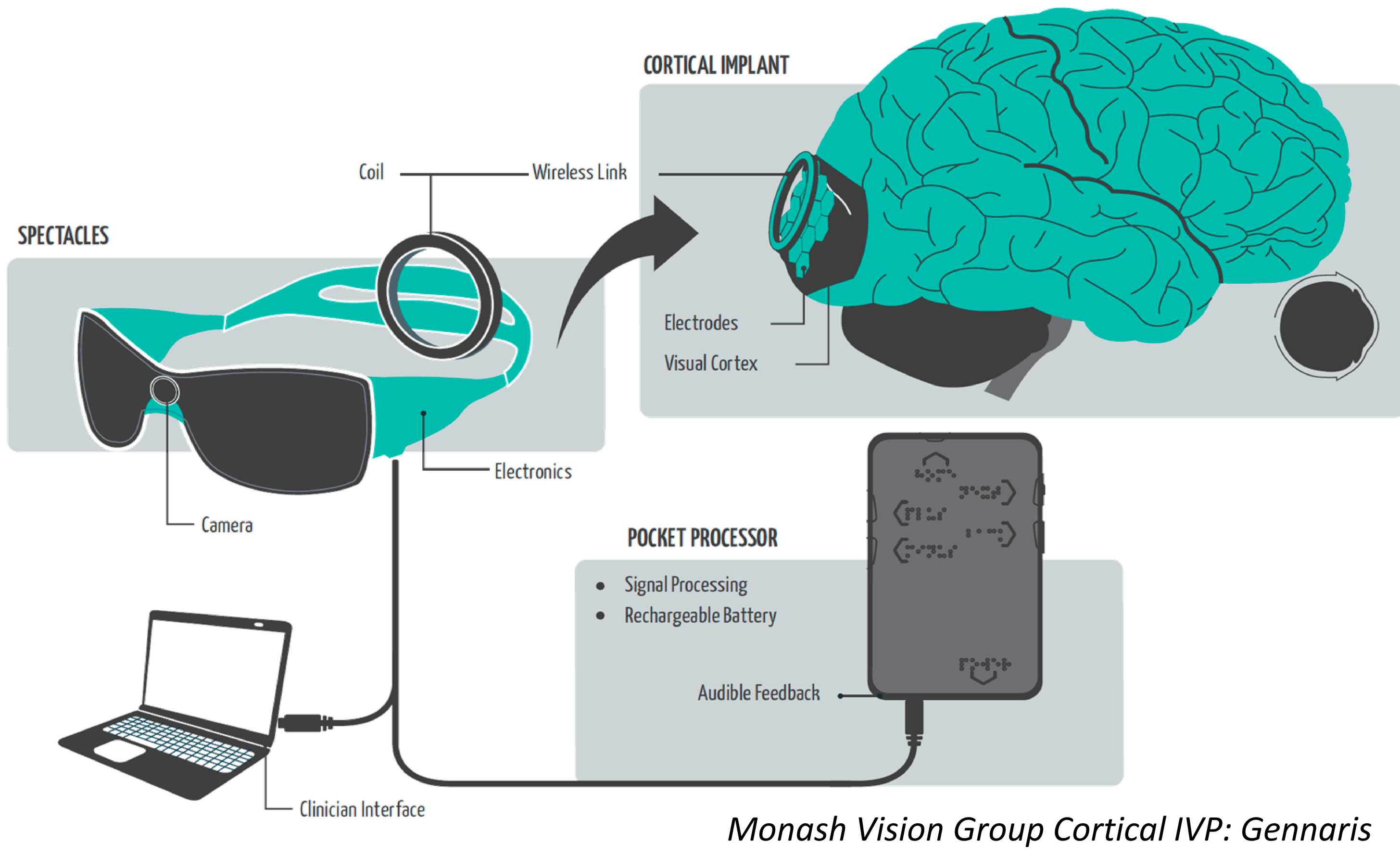
Implanted Visual Prostheses (IVP)

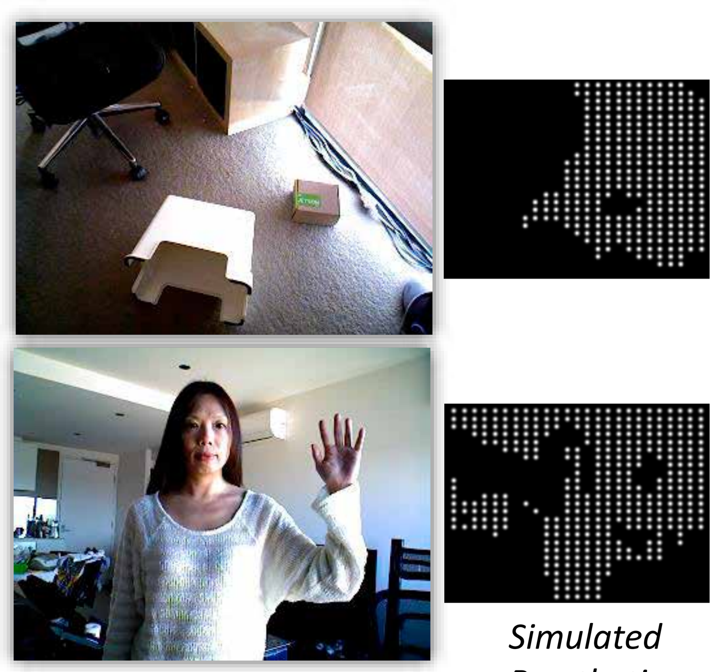
Implanted Visual Prostheses (**IVP**) operate by electrically stimulating the healthy parts of a patient's visual pathway using an array of electrodes. This results in **Prosthetic Vision** consisting of a spatial pattern of **Phosphenes** (bright dots) that vary over time.



Monash Vision Group Cortical IVP: Gennaris

Overcoming the Limitations of Prosthetic Vision

Prosthetic vision has **Low Resolution** and **Limited Dynamic Range**. The Simulated Prosthetic Vision to the right assume a 25x25 electrode array that elicit binary phosphenes by thresholding [1] regions in the camera image. Visual content is heavily truncated.

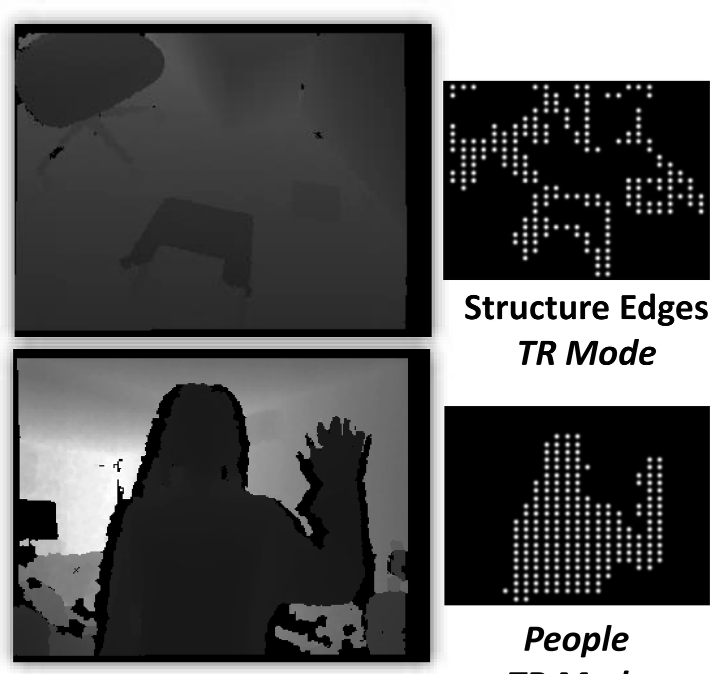


Camera image   *Simulated Prosthetic Vision*

Transformative Reality (**TR**) [2] improves prosthetic vision by using **Computer Vision** to model the world and then *render* these models into phosphene patterns. A patient is able to select different **TR modes** for various daily tasks.

The **Structure Edges** TR Mode uses lit phosphenes to represent 3D structure. It highlights non-planar structures detected by applying PCA to a depth camera image.

The **People** TR Mode highlights people looking at the user by first detecting frontal faces in the camera image followed by body segmentation in the depth image.



Structure Edges ***TR Mode***

People TR Mode

Depth image

From "Backtop" to the Tegra K1

Simulated Prosthetic Vision (**SPV**) is used to non-invasively evaluate computer vision in IVPs. SPV user trials are performed using "Backtop" systems, which combines a powerful laptop in a backpack and a "VR Goggle" with attached sensors. Computer vision (e.g. TR) and SPV let sighted users experience prosthetic vision in real time.

Monash Vision Group (MVG) uses the backtop system below to help **answer psychophysics questions** (e.g. How many phosphenes are needed to detect a face) and let engineers **develop and optimise computer vision software** such as the Depth Edge TR Mode.

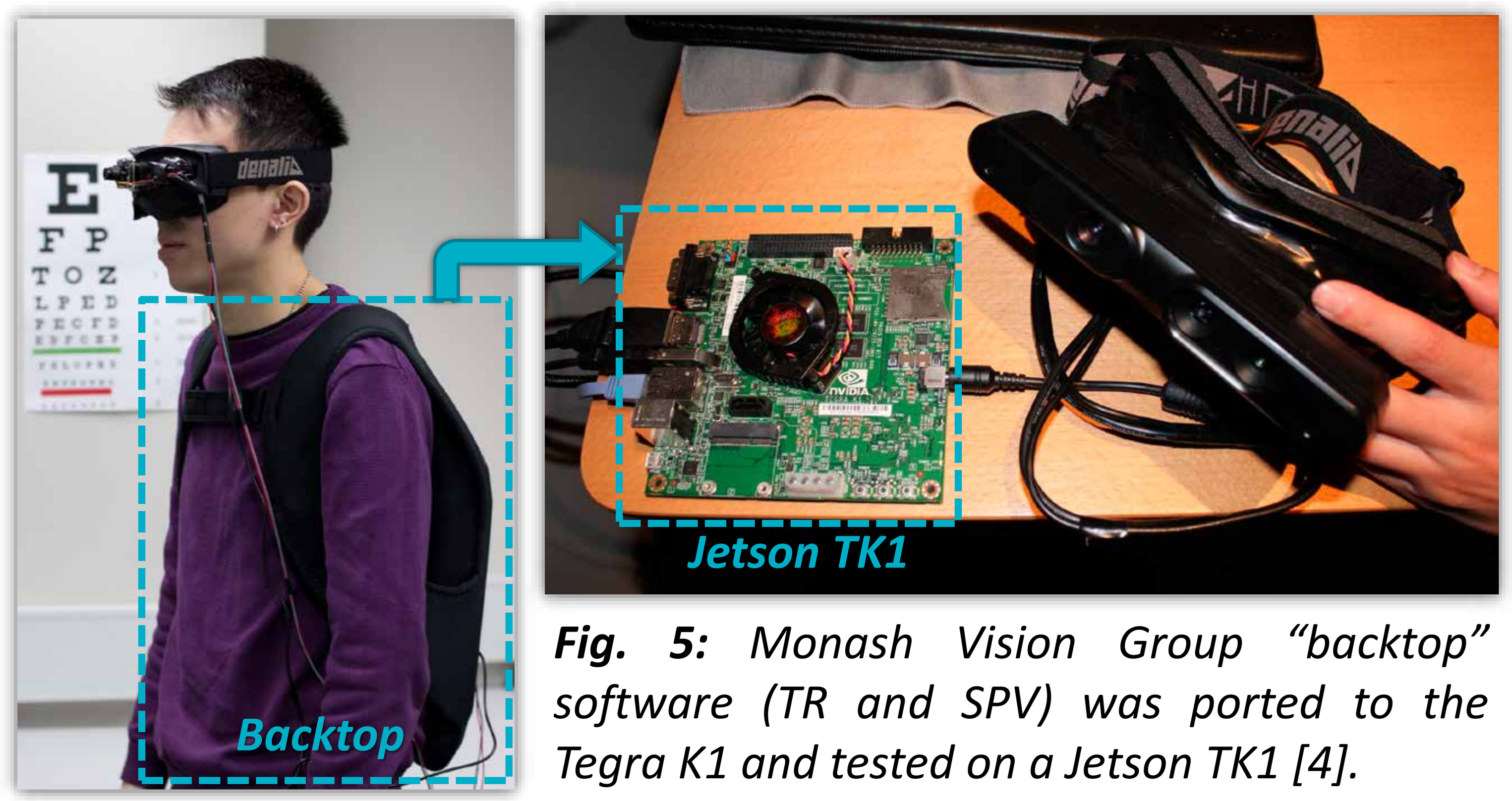


Fig. 5: *Monash Vision Group "backtop" software (TR and SPV) was ported to the Tegra K1 and tested on a Jetson TK1 [4].*

However, the backtop system has limitations. Many advantages have been gained by porting the backtop software to the Jetson TK1:

Backtop Limitation	Tegra K1 Advantage
Heavy 3kg	Light 120g
High power draw & thermal output 67.5W when running software	Low power draw & thermal output 9W when running software
Limited battery life < 1 hour	7.5X battery life
Costly to replicate hardware ~USD$1500	Cheap to replicate hardware < USD$200

In the past, research software designed for backtops is developed separately from production software for the MVG IVP medical device. The latter uses a low power and highly portable ARM-based "Pocket Processor" [3]. The ARM-based medical device platform is geared towards portability but lacks the compute capability of a backtop, which prevents it from running complex computer vision algorithms such as those required for Transformative Reality (TR).

The Tegra K1 may enable the merging research and production software by being computationally powerful yet sufficiently portable.

Optimizing for the Tegra K1

The backtop TR and SPV code was written in C++ using the OpenCV library [5]. The code was ported to the Tegra K1. The following optimisations were implemented, resulting in 30FPS operation.

General Code Optimisations

- Parallelized over multiple threads: Color capture, depth capture, TR Computer Vision and SPV Visualisation
- Compiled with NEON optimisations and linked with OpenCV4Tegra

Structure Edges TR Mode

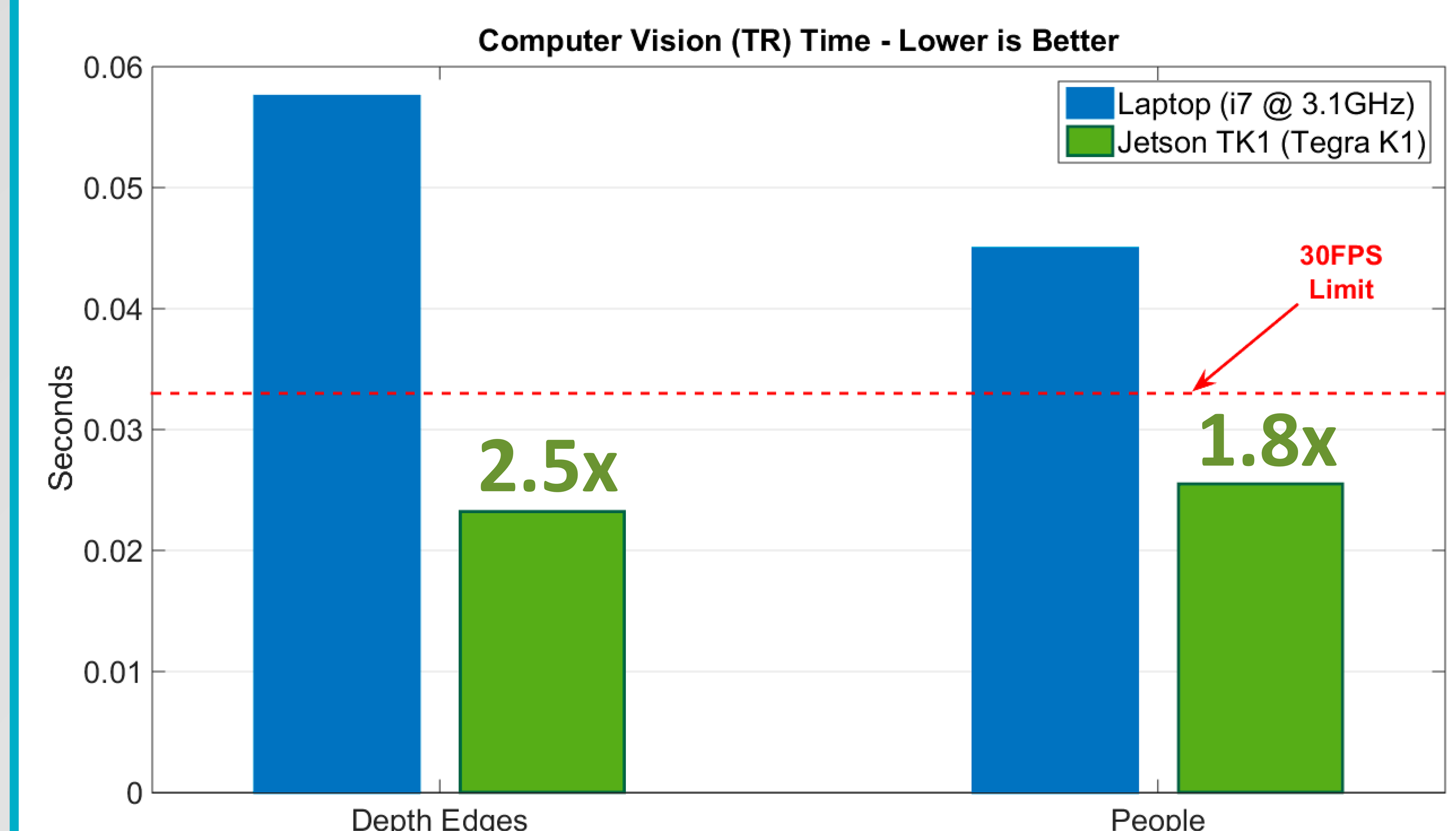
- Bilateral Filter depth pre-processing now uses GPU (via OpenCV `bilateralFilter()`,11x11 patch over 320x240 *float* image)

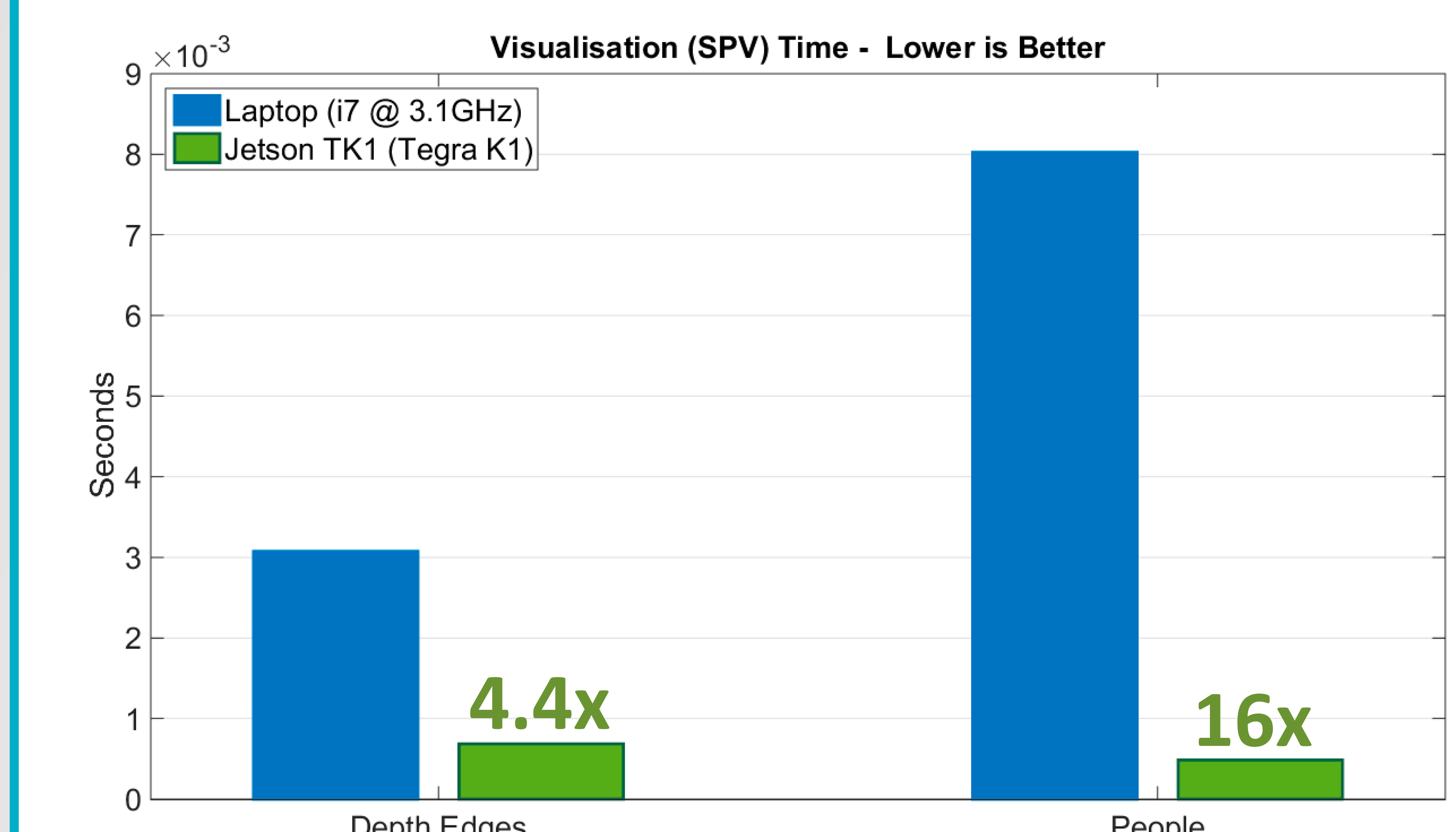
People TR Mode

- Object Detection now uses GPU (via OpenCV using `CascadeClassifier_GPU` class, LBP cascade on 320x240 image)

SPV Visualisations ("For free" optimisation)

- Phosphenes drawn via OpenCV4Tegra optimised functions





This research was supported by the Australian Research Council Special Research Initiative in Bionic Vision and Sciences (SRI 1000006).

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[1] Otsu, N. (1979). A Threshold Selection Method from Gray-Level Histograms. *IEEE Transactions on Systems, Man, and Cybernetics*, *9*(1), 62–66.
[2] Lui, W. L. D., Browne, D., Kleeman, L., Drummond, T., & Li, W. H. (2011). Transformative reality: Augmented reality for visual prostheses. In *2011 10th IEEE ISMAR* (pp. 253–254).
[3] Li, W. H. (2013). Wearable Computer Vision Systems for a Cortical Visual Prosthesis. In *2013 IEEE International Conference on Computer Vision Workshops* (pp. 428–435).
[4] https://developer.nvidia.com/jetson-tk1
[5] http://opencv.org/