Coherent bundle for intra blood vesssel thermal imaging of volunarble plaques.

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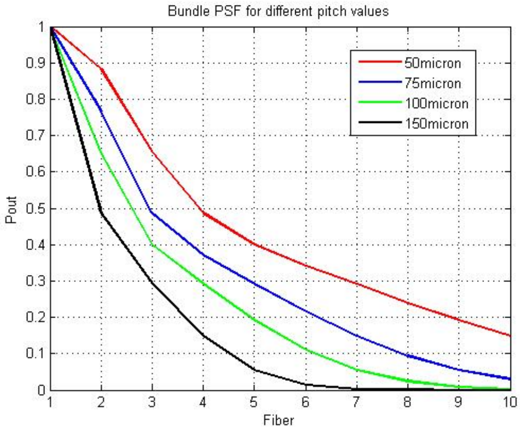
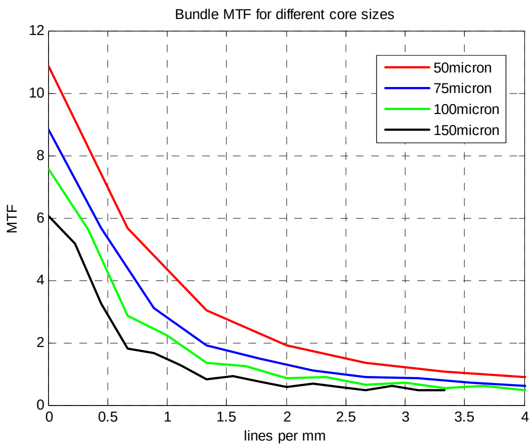
We have been working this year on the resolution limitation of bundles to detect temperature changes in a vulnerable plaque. We have built an IR scanning system to study those and compare with our theoretical findning

1. Simulation of the Bundle Point Spread Function (PSF)

The mathematical tool used for defining the resolution of an optical system is the Modulation Transfer Function (MTF). One approach of calculation the MTF is by first obtaining the system response to an impulse, called impulse response or Point Spread Function (PSF). A Matlab program that can calculate the propagation of a light beam through a single hollow waveguides was used. For each wave guide in the fiber bundle cross section, the entrance angle and energy of light was calculated and a simulation was done to obtain the energy of light at the distal end of the fiber (Pout). The simulation was two dimensional, assuming that the bundle is polar symmetrical for any cross section. The bundle MTF (Modulated transfer function) is the absolute value of the OTF (Optical transfer function) which is the Fourier transform of the PSF. So we took the 4 PSF curves (for 4 different core sizes), and calculated the MTF for these bundles:



Point Spread Function for different fiber pitch values and for bundle diameter 3mm, bundle length 20cm, core diameter 50micron, spot distances from bundle 10mm, dielectric layer thickness 2micron



As the resolution of the bundle is defined by the point where the intensity of the MTF is reduced to half of its maximum value, from this graph we can see that the resolution of a 50 micron core size bundle is around 0.7 lines per mm.

2. Temperature response of a single fiber

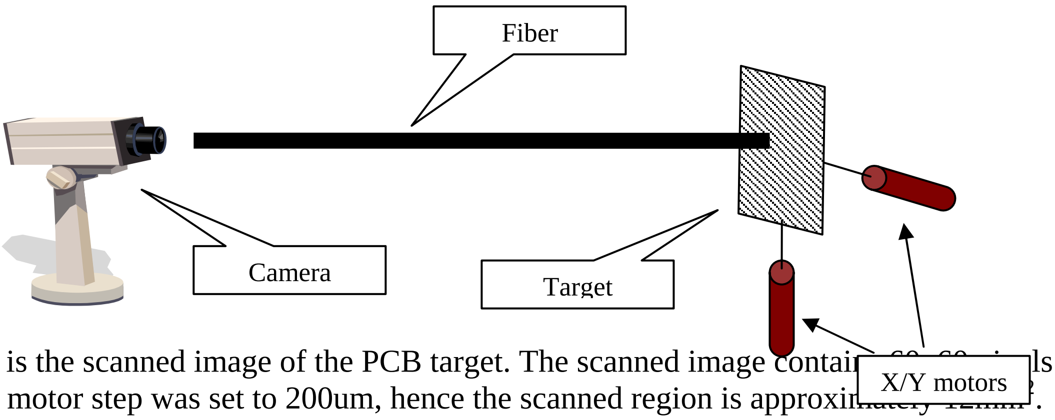
In this stage we tried to develop and validate a mathematical model that will estimate the temperature response of a single fiber and we conducted an experiment which validated our model. We were able to reach the following equation, which gives a clear linear relationship between the target temperature (T_p) and the temperature detected by the camera (T_c). We then showed that the slope k can be reduced in the following way and depends only on the fiber transmission.

$$\Delta T_p = \left(\frac{\pi \cdot r^2}{T_R \cdot F \cdot A} \right)^{\frac{1}{4}} \cdot \Delta T_c$$

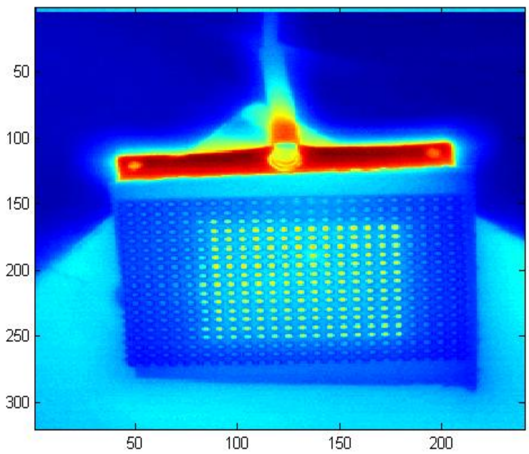
$$k = \left(\frac{T_R \cdot \frac{\pi \cdot r^2}{A} \cdot A}{\pi \cdot r^2} \right)^{\frac{1}{4}} = (T_R)^{\frac{1}{4}}$$

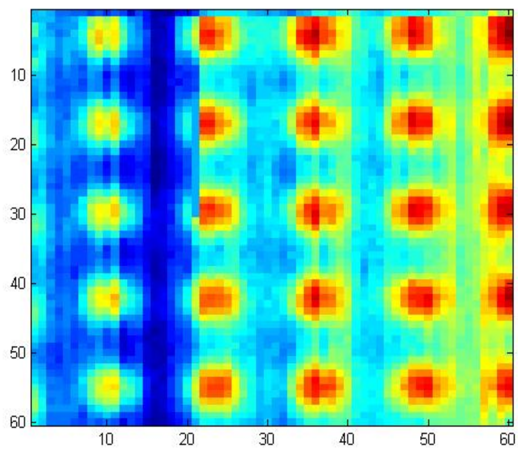
3. Thermal Imaging using a Single Fiber Scanning System

One of the imaging targets used was a PCB board constructed of 1mm holes, which was placed in front of a hot plate heated to 45°C. The target was connected to 2 motors, which provided the X/Y motion needed for the scanning process. A 1mm core diameter hollow wave guide was placed with its distal end approximately 2-3m from the surface of the target. The Thermal Camera was focused to the proximal end of the fiber, allowing us to capture the IR energy coming out of the fiber. LabView program was used in order to control the motors and the camera. On every motor movement an image of the proximal end of the fiber was taken, the temperature was estimated by calculating the average pixel value of a region inside the fiber core and this value was used as the pixel value in the construction of the scanned image. This is an illustration of the single fiber scanning system:

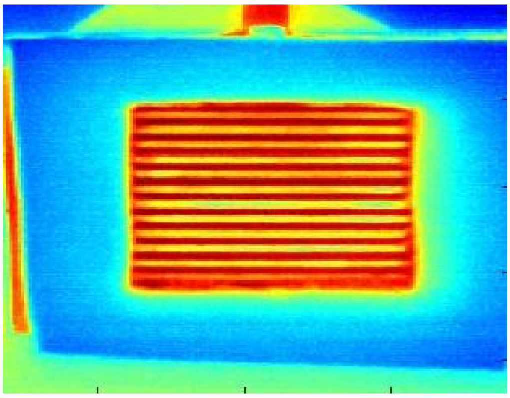


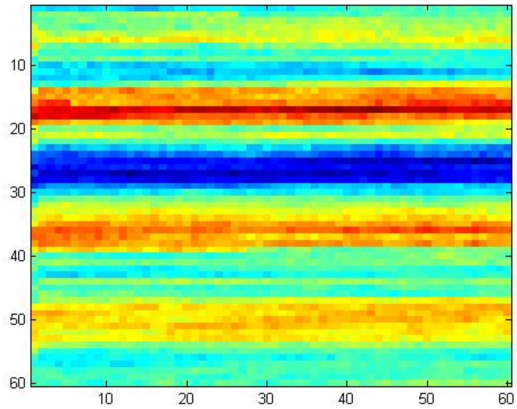
Bellow is the scanned image of the PCB target. The scanned image contai[illegible]ls and the motor step was set to 200um, hence the scanned region is approxi[illegible].



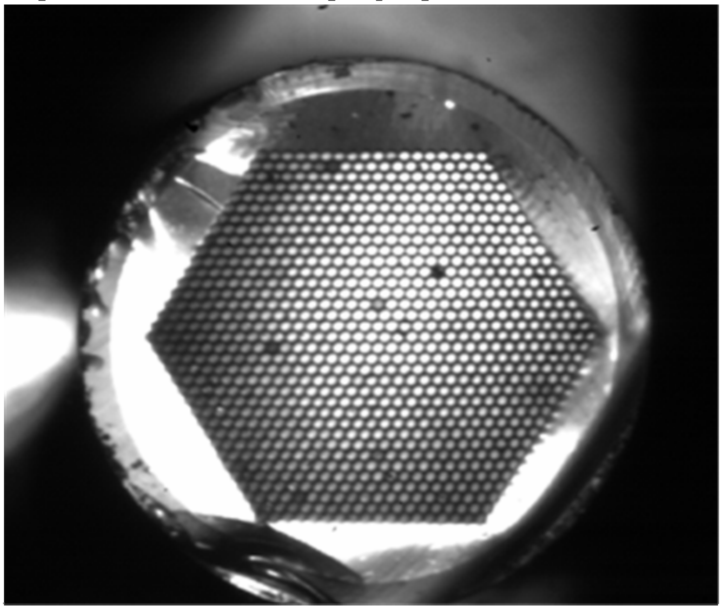


An additional IR target of 1.5mm wide bars was used. Bellow you can find the thermal image of the bar target as seen by the thermal camera.





The bar target as seen directly by the Thermal camera (Left).The scanned image of the bar target (Right). The images are 60x60 with 200um step distance.
The next step is to apply these finding in the following bundle that we created. It will be inspected in a vulnerable plaque phantom that will be built this year in the lab.



900 fibers HGW