

SLP: A Zero-Contact Non-Invasive Method for Pulmonary Function Testing

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In this paper we introduce a novel non-invasive method that uses structured light to perform pulmonary function testing (PFT). PFT is the general term for a range of clinical tests that can be performed on a patient in order to assess respiratory status. The technique, called Structured Light Plethysmography (SLP), produces an estimate of chest wall volume changes over time.

SLP is non-invasive and does not require the placement of markers onto the body [2, 3]. The system has been used to monitor breathing patterns of both human subjects as well as sedated domestic animals in both experimental as well as clinical settings.

The technique works by projecting a grid pattern onto a subject's chest area, while in seated or supine position (see Figure 1). Two cameras, placed at different positions and angles (both unknown), record the subject's chest area. Grid pattern intersection points (*i.e.* grid square corners) are tracked, and brought into correspondence.



Figure 1: The grid pattern (left). The corners of the squares are ‘grid intersection points’ and there are $w_{\text{grid}} \times h_{\text{grid}}$ (23×28) of these. The grid pattern as projected onto a subject (center), and after identifying grid intersection points (right).

A self-calibration algorithm then infers the internal and external parameters of both the two cameras as well as the projector, using a subset of the point correspondences over time. Camera orientation and translation are recovered using a technique proposed in [4]. This method optimises an objective function iteratively using closed-form formulae of the gradient of this function w.r.t. the unknown parameters. This work is extended to include the recovery of the intrinsic K matrix. We formulate the K matrix in terms of the focal length (f), camera sensor width (w_s) and pixel aspect-ratio (r) as these are relatively intuitive parameters to work with. We can find good *a priori* guesses for these parameters. The extension adopts a two-stage sampling and refinement approach for estimating f , w_s and r . In the first stage we find a coarse approximation to K using a simple sampling approach. In the second stage, this approximation is refined by taking the coarse approximation as a starting point for numerical optimisation.

Next, the chest wall is reconstructed using the point correspondences and the camera calibration. A surface reconstruction is generated by building a quad mesh from the reconstructed 3-D world positions, which is straightforward given the grid topology. In order to calculate volume we assume that each quad lies in the convex hull of its four corners.

To isolate the chest area we consider the grid points of a single frame of the reconstruction as pixels in a binary image, where black means a

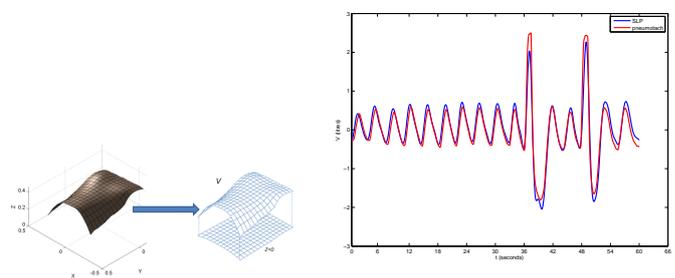


Figure 2: The ‘chest wall volume’ V as calculated by SLP (left) and a typical example of SLP volume data superimposed on pneumotach volume data of the same measurement.

grid point is missing in that frame, and white means it is known. We then choose the rectangular area within this binary image that contains the grid points that lie on the chest via a heuristic method. The grid points that fall outside this area are discarded from the reconstruction.

To fill in missing grid points we estimate such a point using both temporal as well as spatial (*i.e.* neighbouring) information from the existing reconstruction. For each frame of the reconstruction, we identify the missing points and estimate these independently.

Finally, volume changes of the chest wall over time are calculated from the reconstruction and knowledge of the work bench plane; *i.e.* the seat back or mat on which the subject is resting. We use Gauss’s Theorem to compute the volume from the chest wall. An absolute length scale is recovered from an object of known dimensions attached to the work bench. A prototype instrument was built at Cambridge University Engineering Department (CUED). This instrument has been used in several (pre-)clinical tests, and is the starting point for a commercial rig currently under development [1].

The system has been used to perform SLP measurements on more than 60 healthy subjects. During measurements subjects breathed through a pneumotach spirometer (the standard device for PFT) to allow for volume comparisons. The SLP volume data correlate very well ($R^2 = 0.91$) with that of a spirometer. See Figure 2 for a typical example of volume over time for both SLP as well as a spirometer.

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