RECONSTRUCTION OF TRILEAFLET HEART VALVE LEAFLET MOTION BY USING PHOTOGRAMMETRY AND BIQUINTIC FINITE ELEMNET METHOD

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Abstract

The purpose of this study is to capture the transient geometry of an artificial heart valve leaflet surface using dual camera stereo photogrammetry in a fluid flow loop that closely simulates the real physiologic operative conditions. An enhanced numerical method is developed to reconstruct the three-dimensional deformed surface.

The artificial heart valve used in this study is a newly developed trileaflet polymeric heart valve under test at Florida International University's Cardiovascular Engineering Center. The successful implantation of mechanical and bioprosthetic heart valves in patients with diseased or damaged natural valves represents a tremendous medical achievement. Nevertheless, researchers in both academia and industry continue to investigate new modifications and design changes to improve valve performance and durability in both pediatric and adult patients. As an example, considerable effort is now being directed at the development of a synthetic flexible membrane heart valve at Cardiovascular Engineering Center of Biomedical Engineering Institute at Florida International University. Synthetic flexible membrane trileaflet valves offer natural valve hemodynamics with the potential for sufficient durability for long-term use. Unfortunately these valves have not been successful to date because of long-term material degradation in vivo through a combination of oxidative reactions with blood and the high dynamic tensile and bending stresses borne by the material. The objective of the project is the investigation of a synthetic flexible membrane heart valve design with leaflets that mimic natural leaflet geometry and structure: elliptically shaped leaflets fabricated from a composite material (polypropylene fibers embedded in a non-oxidative polymer, polystyrene-polyisobutylene-polystyrene (SIBS)). In the natural valve leaflets, collagen fibers reinforce the tissue and provide the requisite structural integrity. Natural heart valve leaflet tissue is a composite material that includes collagen fibers in bundles, which are arranged in a special structure and orientation, which provide optimal mechanical behavior by eliminating the principal stresses in the leaflet because the orientation of collagen bundles coincides with these stresses. The proposed novel artificial heart valve design incorporates a composite material, polypropylene threads embedded in SIBS, with the thread architecture and leaflet geometry mimicking the natural valve leaflet.
One of the leaflets is marked with approximately 100 0.3 mm diameter India Ink dots for quantitative surface analysis. From the acquired image sequences, 3-D coordinates of the marker matrix were derived and hence the surface contour of each opening and closing phase during one cardiac cycle were reconstructed. We will make mock physiological flow loop. The valves will be mounted in the aortic position of the Vivitro System left heart and systemic circulation simulator. This system includes a processor-controlled stepper motor that drives a piston cylinder, forcing contraction and relaxation of the left ventricular sac. The mitral and aortic valves are mounted in relative anatomical positions, and the aortic outflow track includes the sinus of valsalva. The remaining flow loop includes models of characteristic and peripheral resistance and compliance to reproduce systemic physiological flow and pressure waveforms. Aortic flow is measured with an electromagnetic flow probe and meter mounted just below the aortic valve plane. Artria, ventricular, and aortic pressures will be measured with catheter-tipped piezoelectric pressure transducers. Data is acquired and stored with the MP100 data acquisition system and software.

Dual camera stereo photogrammetry [1] uses two identical cameras to focus on the same object (BHV leaflet) to simultaneously acquire images of the marked leaflet from two different angles. Each photo have the size of 9.33 mm(width) x 5.87 mm(height). The spatial resolution is 14 µm x 14 µm. The focal length of endoscope is 3 mm. The endoscope lenses were calibrated for photogrammetry by imaging a target pattern [2] immersed in solution (36% glycerin , 0.9% saline).

The surface geometry dynamics of anatomic structures can reveal aspects of their mechanical properties. A new improved surface fitting method was developed and used [3]. Our mechanical analysis requires accurate time dependant quantification of three-dimensional surface geometry. Surface fitting of a network of point coordinates determined by photogrammetry was performed. For the modeling of contiguous surfaces, interpolating surfaces based on finite element shape functions

have proved appropriate. Previous work used surfaces having C^1 continuity. C^1 continuity is continuity of the first derivative or slope. This is not sufficient for analysis of structures that experience significant flexure. Here I present generalized hermite biquintic interpolation functions for geometric analysis that gives C^2 continuity, that is, continuity of the second derivative or curvature. A time series of the data sets gives surface velocities and displacements useful in product design verification [4].

Valve leaflet motion will be measured only at the normal physiological heart rate(70beats/min) and cardiac output(5 liters/min). Dynamic leaflet motion will be monitored using the dual camera stereo photogrammetry method described in Gao et al.(2000). The aortic valve mounting chamber will be modified to obtain an optical window into the aortic channel. The valve leaflets will be marked with a set of fiducial points at known positions. Two CCD cameras will acquire images of a single valve leaflet at a relative angle of 15° between the optical axes. Images will be acquired at a frame rate of 30 Hz by a frame grabber(Coreco Viper-Quad). A short-pulse(3 μs duration) strobe light triggered in synchrony with the imaging system will illuminate the field and freeze the leaflet motion. The image pairs will be used to reconstruct the 3-D leaflet surface using the algorithm described in Smith et al.(2000).From this data local displacement and velocity of the leaflet surface can be computed. Calibration of the software and camera system will be done preceding valve testing using phantom shapes of known dimensions to provide the required dimensional calibration.

The ultimate goal is to compute the local displacement and velocity of the leaflet surface in the leaflets during opening and closing. To achieve this goal, first of all, we have to make accurate surface fitting of a heart valve leaflet. Performance of the valves will be assessed by the mean pressure drop across the valve during forward flow and the percent regulation during valve closure and while it is closed(leakage). The measured velocities and displacements will provide a check on results of a parallel effort which is implementing a finite element simulation of valve dynamics.

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