Chapter 7

Conclusions

7.1 Remarks, Possibilities, Future Work and Applications

The procedure proposed in Chapter 6 adds functionality to the original elastic surface registration procedure implemented from literature. Feature registration gives an improved initial condition to the surface registration procedure. Not allowing the untrusted registration to unmatched feature areas reduces the need for a generic mesh to be exactly deformed into a target representation. This is helpful when topological inconsistencies between the generic and target shape could pose a problem.

Apart from some of the improvements made, the uniqueness of the registration result and it's dependence on user input is cause for concern and should receive due attention. The variation in masticatory induced stress for example due to prognathism can't be quantified without proper measures in place to describe the accuracy with which a target is represented. A difference in topology between the deformable mesh at the end of registration, and the target it should represent, makes it difficult to quantify how well a registration is performed and where further improvement is required.

Various possible improvements on the registration procedure or a similar elastic registration procedure could be addressed in future work. Many of the processes addressed in this report could be improved and only some of the more pressing changes are highlighted in this section. These improvements should give added reliability and robustness to the registration procedure while producing unique, usable registration results. Possible areas of improvement and how it could be beneficial include:

- Added reliability should be introduced into the registration process. One possibility is to investigate an improved correspondence between points. It would be beneficial to better determine where points on the deformable mesh should register. Using something like the shape context as described in Appendix C to do registration could be beneficial. These methods compare the context of each point within the greater shape to match up areas on the deformable and target mesh that likely represent the same position with reasonable accuracy.

- The possibility of comparing reduced model shapes or surface segments could also prove beneficial. A few possibilities exist to compare and register shapes with reduced dimensionality:

  - Most designed geometries can be represented as a combination of various primitive shapes such as boxes, spheres and cylinders. If possible, patient specific shapes could be approximated in this manner for initial crude comparison and registration.
  - The automatic segmentation of mesh surfaces using curvature information could give the same benefit. If this is done the overall surface segments can be compared or used in the approximation of base geometries that make up the patient specific geometry.
  - The use of RBFs to construct an implicit surface representation of a discretised surface is used to approximate and extract the overall features of various surfaces by Ohtake *et al.* [45]. Using a combination of mathematically defined smooth functions to represent a shape rather than the discretised surface mesh, it could be possible to compare a generic and target shape on this function level rather than using and comparing the mesh representations. This could be done to various degrees of accuracy by constructing the representation with more implicit surfaces for example if higher accuracy is required. If it is possible to compare the implicit surface representations instead of mesh representations it could be possible to find a unique registration to deform one implicit representation into the other. The spatial deformation field obtained in this manner could then be applied to the mesh.

- The use of a finite element mesh and improved physics during the registration process is another area that deserves attention. Using a better defined deformation model than the iterative application of a Gaussian weighted smoothed deformation field could produce improved results. The possible use of better registration techniques along with a better deformation model could better capture the physics required from one state to another in the deformation or alternate state of the same soft organ geometry for example. The use of a hyper-elastic [65] material model or allowing something like "work hardening"[1] to counter element inversion could also be investigated. The use of a single mesh to represent all geometries of concern should remain an integral part of the process deliverable. If element inversion is simply not allowed during mesh deformation, there would be no need to untangle the mesh or remove inverted elements.

- The registration and deformation procedure should be attempted using optimisation. If a finite element mesh is deformed to better represent a target surface or the boundary of a target computational domain for example, the optimum registration should be obtained that represents the target with induced strain at a minimum. If this can be achieved, a unique registration result should be guaranteed.

Future applications of the improved registration procedure are numerous. A few attractive applications are listed that could be pursued once a reliable elastic registration procedure is available:

- The registration of a large sample of similar geometries. This should be done with a procedure that always finds the same unique result for a specific target geometry or computational domain. It would be undesired to extract the principal modes of variation in a statistical sample of registered subjects only to have these be a function of the registration procedure or some user input specified. The change in flow field or stress due to a specific mode of variation could be inspected once this is achieved.

- Registration to transient data of the same geometry. If transient data is available for a heart, an artery or some other soft organ geometry, fluid struc-

[1]Work or strain hardening in numerical methods approximate what happens during the cold working of metals. It is the strengthening of a metal by plastic deformation where the strengthening occurs because of dislocation interaction within the crystal structure of the material [27].

ture interaction or intra-operable deformation could be studied. This should also be done in a least strain manner if at all possible. The intraoperative[2] tracking of deformation is a major deliverable in patient specific modelling and research. For that reason, this application of the registration procedure should prove useful.

- Research into obtaining *in vivo* material properties for use in numerical modelling [41]. Obtaining material properties *in vivo* could be pursued along with the benchmarking and validation of fluid structure interaction (FSI) simulations. As an example, the boundary of an artery could be tracked and described numerically after a reliable registration procedure is performed on transient geometric data. If the boundary conditions and the movement of the computational domain boundary is known it could be possible to extract material properties from some kind of inverse FSI type simulation. The material properties extracted can then be used in further patient specific modelling.

[2]During surgery