Chapter 4

Conclusions and Future Work

This work concentrates on assembly sequence planning and assembly path planning. It is an attempt towards achieving automatic assembly through automatic programming. The assembly sequence heuristic and contact state recognition through force/torque measurements presented in this thesis can be used as support tools to aid some crucial decision making with regard to sequence planning and contact state recognition. In this section, we summarize the results of this thesis and highlight some major contributions. We also make recommendations for future work in the field of assembly sequence planning and assembly path planning.

4.1 Assembly Sequence planning

Assembly sequence planning dealt with optimizing assembly sequences for any given set of components (of a product) to be assembled. A heuristic to find a single optimal assembly sequence was derived based on the liaison technique developed by Abell et. al. (Abell et. al., 1991). The results of the optimization gave the preferred directions of assembly for each component. Thus components/subassemblies were categorized based on their preferred directions of assembly. This fixed the orientations of the parts/subassemblies before assembly at the workstation and the synthesis of a “universal” gripper was demonstrated.

The liaison technique was used to enumerate all the possible assembly sequences based on precedence constraints. Applying constraints to avoid some unstable assembly sequences reduced the number of feasible assembly sequences. For the remaining sequences aggregate IDs were calculated based on the individual IDs of each component and different positions of the base fixture. The sequence with the least aggregate ID is the optimum sequence for the assembly. The optimum assembly also gives the preferred orientations of the components. Using this information, the feasible grasping features of each component is cataloged. The feasible grasping configurations are scanned through to design of a ‘single’ gripper that is able to handle all the parts involved.

As pointed out in the section 2.4, ID evaluation is a manual process although it is reasonably accurate (Woo and Dutta, 1991 and Yang and Sturges, 1992). Hence, the heuristic presented can be used effectively for processes that involve small search spaces. However, when the problem grows in terms of the number of components involved, manual ID evaluation for each component and each assembly direction can become cumbersome. Thus, there is a need to automate the process and this will be thrust of future research.

4.2 Assembly Path Planning

The theory of principal contacts (PCs) and contact formations (CFs) has been validated. Contact state experiments have been conducted to prove that a change of state from one PC to another is usually associated with an abrupt change in the general contact forces. Only the peg-in-corner problem (2D case) has been addressed in this paper. The main contribution through the contact state experiments has been categorizing neighboring contact states as distinguishable or indistinguishable through force/torque measurement alone. The force/torque that most easily distinguishes a given pair of neighboring states has been cataloged. This information can be used in automatic assembly programs that aim to automatically generate and execute assembly path plans.

The experiment itself involved establishing a range of measurable values of the forces/torques for different contact states in the peg-in-corner problem. Also, the forces/torques obtained for different contact states are tabulated such that the changes in the general contact force are represented as ratios. From these ratios, forces/torques that help in distinguishing neighboring contact states have been identified and cataloged. We believe that contact state recognition will be much simpler with force/torque inputs along with the position/orientation information. However, more work needs to be done, especially in the 3D environment. The next step, however, is verifying the theories of PCs and CFs for a multiple peg-in-corner problem before attacking the 3D problem. This could be the thrust for future research.