Chapter 7

CONCLUSIONS AND SCOPE FOR FUTURE WORK

This chapter presents the conclusions of complete research work undertaken in the specific field of robotics which includes design and planning of a workcell. The research study presented in this thesis, certainly adds new areas for further research and based on that some scope for future work is also presented in the following section.

7.1. Conclusions

The thesis addresses some crucial issues related to robotic workcell and presents novel solutions which are accurate and easily implementable at the industrial level. Various problems undertaken in this study have been solved by using the self-developed point cloud simulation approach. The literature survey pointed out some salient problems occurring in the robotic workcell, and it is demonstrated that the point cloud simulation approach has been able to solve them successfully.

The first problem is the improper modeling of machines and robots of the workcell which is fixed by using the actual geometric models developed by point cloud data matrices through programming in Matlab. The next problem is the complex mathematical formulation which requires high computational power that is resolved by using axis-aligned bounding box method to create an approximate model of the point cloud data matrices which are directly used in optimization problems. The inefficient collision avoidance techniques were generating unimplementable solutions which require further calibration and indirectly increase the workcell setup time.

This problem is fixed by using precise collision avoidance algorithm for point cloud models. The point cloud simulation approach also reduces the expense of using the costly robotics planning packages which were equipped with GUI, this approach generates the visual images of the developed results. Further, the multi-robot cellular system has also been least utilized in industries, therefore in this work a novel approach for transforming parallel single robotic workcells to multirobot workcell has been developed. This multirobot workcell design has been expected to ease the complex multirobot workcell architecture and promote its application in industries throughout the world.

The important conclusions drawn from the present research work are as follows:

- A new approach has been proposed for industrial robotic workcell which generates solutions for layout design and trajectory planning problem associated with it. In this thesis, the proposed approach is named as point cloud simulation approach.
- This research work presents an innovative methodology to transform a single robotic workcell into a multi-robot workcell using the point cloud simulation approach.
- Three dimensional visual images of the optimal solutions is an advantageous feature of the point cloud simulation approach. The point cloud models of each object of the workcell can be clearly observed by visual image named as point cloud map. These point cloud maps also provide the feedback of the solutions and possible corrections can be suggested.
- Layout design for single robotic workcell by point cloud simulation approach produces 59% lesser joint angular motion. This significant improvement is due to the fact that the accurate point cloud models saves a lot of robot workspace and thus

gives tangible domain to search the best solution. Moreover, the multirobot layout design is much benefited by this approach.

- Multirobot layout design by the developed approach is a novel research of this thesis work. It saves expenses by reducing machines required and results in 49% saving of floor area as compared to the single robot layout.
- This new layout design processes also reduce the combined effort of robots by 36% comparative to similar number of robots in single robot layout.
- Point cloud simulation approach gives a new dimension to the trajectory planning problem of the robotic manipulator. This approach solves the complex trajectory planning problem with the real data of the workcell objects.
- The fifth degree B-spline profile is found to be the most optimal interpolation trajectory profile under realistic constrained problems. Also, 39.78% reduction in the jerk supports the continuous and smooth motion of the end-effector generated by the B-Spline interpolation.
- The trajectory planning and layout design are inter-dependent on each other as changing machine location also change the trajectory of the robot operating on it.

The point cloud simulation approach works on the kinematic modeling of the machines and robot, and its entire mechanism has been demonstrated in chapter 3. This approach has been designed to re-plan an existing industrial robotic workcell and can also be used to establish a new robotic workcell. The input required for this approach is the CAD models and the kinematic relation between relative moving parts of the objects. Several algorithms in Matlab language have been developed to obtain the final working point cloud model which iterates to obtain the optimal solution. In this process, the three basic necessity of efficient workcell design and planning, i.e. realistic working environment, implementable optimal

solutions, and feedback of the generated results have been achieved systematically in a single planning approach. The applications of this approach have been demonstrated in the next three chapter taking an industrial case study.

The first application of this approach has been presented in Chapter 4, in which the layout design of a single robot workcell has been designed. The data for the case study has been collected from the M/s Electrosteel Castings Ltd., Dhanbad, Jharkhand. The modeling of machines with actual geometry and dimensions has been performed, and the optimal layout of the existing industrial workcell has been generated. The optimal solutions are obtained by using minimum robot joint angular movement criteria, which reduces the power requirement, and increasing the life of the joint actuators.

The next application, concerns with the establishment of new multirobot industrial workcell whose layout has been designed by using data from the single robot workcell. This is the historic development in the field of robotic workcell design and expected to be a revolutionary methodology to increase multirobot workcells in the manufacturing industry. In this application, the precision, and the realistic point cloud modeling has been used to fit the machines in the least possible space. The layout design of multirobot workcell has been developed by maintaining the productivity as of the parallel single robot workcells. This objective has been achieved by adjusting the motion sequence of robot for a cycle and increasing the operating speed of respective machines.

After successful application of the point cloud simulation approach for layout design, it was applied to the trajectory planning of robot. The trajectory of the robot is a crucial factor, affecting the time, cost and effort consumed in the production by the workcell. Chapter 6 discusses the procedure adopted for planning the trajectory of the robot's end-effector. Finally, the research work presented in this thesis strives to solve the

challenging issues in the field of robotics and cellular manufacturing with great emphasis on accuracy and practicality of problems and solutions. Further, the next section presents some possible fields where the point cloud simulation approach can be applied.

7.2. Scope for Future Work

The point cloud simulation approach is a generic technique for design and planning of the robotic workcell. This approach is open to be programmed by other languages and supports different algorithm to generate the desired result. Systematic analysis of the proposed approach and its various application present before us a vast scope for further research which has been summarized below:

* The problem of layout design can be applied to the typical industrial scenario, considering more number of moving and non-moving machines. This may inspire to develop multiscale layout planning scheme for the industries.
* The multirobot workcell layout design and transformation may starts a new era in the multirobot cellular manufacturing, and multirobot trajectory planning can be the next step to enhance its performance.
* The next issue highlighted in this thesis is the trajectory planning of the robotic manipulator under realistic operating conditions. There is a strong possibility to the area of path planning under different optimality criteria.
* The open license GUI package can be developed which can also increase its application to the non-industrial field also such as navigation, construction, etc.
* The GUI development can also give the commercial touch to the approach and build trust among the users.