CHAPTER 5
SUMMARY

The theme of this study is the possibility of coupling a robot arm with a patient-bound tool without exerting forces on the patient during robot assisted orthognathic surgery.

Dentofacial deformities afflict a considerable percentage of the world population, for which many seek treatment. While orthodontics can usually correct dental occlusion, corrective orthognathic surgery may be necessary to correct misalignment of the jaws. At some stage in surgeries involving the repositioning of the maxilla, the correct position of the upper jaw in relation to the base of the skull needs to be found. An accurate repositioning is extremely important not only for aesthetical reasons, but also for correcting malocclusions, which improve the ability to chew, speak and breathe.

Orthognathic surgery has evolved into a relatively common procedure with a high degree of predictability over the last few years. Technical advances, such as rigid fixation techniques, bone graft harvesting techniques or bone substitutes, have further enhanced surgical success in the area. However, despite significant improvements in technique there is still room for improvement. Presently the procedure to obtain the correct dental occlusion is done by means of a plastic splint. This splint defines the correct position of the maxilla in relation to the untouched mandible, although only in the horizontal plane. The repositioning, drilling and fixation of the maxilla in the vertical axis remains a difficult task, which is carried out manually by supporting the mandible in a stable position approximating as much as possible to a “normal” situation. Vertical displacement measurements are taken with a compass or ruler and compared with the pre-operative surgical plan. The conventional method has no assistance of computational means and therefore the main source of inaccuracy is the dental splint and the human eye.

For this reason new techniques aiming to deliver an accurate implementation of the operation plan have been developed. Navigation and augmented reality systems help to transfer the pre-surgical plan by comparing the actual patient with the information presented on the screen. However, as described by several researchers even if a bone fragment navigation system could achieve sub-millimetre accuracies, the applied accuracy in the hands of a surgeon is estimated to be two to four mm. The repositioning is highly human-dependent since the surgeons are unable to achieve the accuracy, precision and stability of a robotic arm. Consequently a robotic system was developed to support the surgeon intra-operatively and facilitate the accurate transfer of the pre-surgical plan into the operation theatre, minimising human-dependent errors.

This robotic approach intersects the conventional workflow by pre-operatively recording the transformation to be executed; registration with the patient before separation of the maxilla; and finally pointing to the target position after down-fracture of the maxilla. After analysing the intersections of this robotic approach with the conventional workflow it was primarily acknowledged that there was a requirement to place the robot away from the surgical site during most of the surgery and only seldom bring the robot to the patient. This meant that it was necessary to couple and decouple the robot arm multiple times from the patient-bound tool. However, it remained unsolved the problems associated with coupling the robot and the tool in an intuitive, simple way that minimises any hazard to the patient.

The known magnitude of inaccuracies in optical tracking technologies lead to contact forces being applied to the tool during coupling, and also on to the patient. These forces raise serious safety concerns especially when the maxilla is mobile, where such uncontrolled and unexpected forces are naturally undesirable. Additionally, intuitive handling is hindered with the usage of external tracking devices which require a constant line-of-sight to the markers, and their relative large size. For these reasons a new approach to the coupling problem was researched.

In this study, the use of a camera embedded in the end effector achieved a better coupling solution. The camera placed on the robot arm is closer to the optical markers, allowing a higher tracking accuracy, which in turn enables a safer coupling without the application of force on the patient. With this method the coupling problem was reduced to a robot-arm / moving-target relative positioning problem. This relative position is acquired by extracting the information from the circular markers on the surgical tool. And the robot arm position is calculated to move relative to the target. In order to maintain registration and exact translation of the pre-planned maxilla repositioning, an exact matching of the interfaces between tool and end effector was designed. The developed surgical tool is fixed to the patient’s teeth with similar ease as conventional dental splints. The force control mode provided the intuitive feeling of guidance, as the surgeon steers the robot to the approximate location of the tool. Due to the nature of the surgery room this coupling method was further enhanced with a specific mechanical solution to maintain sterility.

The image processing concept used for tracking was successful in discerning the correct 3D position and orientation with a reasonable amount of error. The path that minimises tracking errors was researched and found to be the lowest when approaching the target on the perpendicular axis of the target plane, given by the normal vector and passing through the centre point of the target.

Zero force coupling is achieved when the robot is able to seize the tool without collision. To assert patient safety, measurements of forces at the tool were carried out. Additional tests with the light-weight robot LBR-3 (KUKA Roboter GmbH, Augsburg, Germany) contributed the information for realistic surgical conditions, drilling and screw fixation, with both plastic phantom and swine cadaver. It was observed throughout repeated experiments that it is possible to couple without exerting force on the patient.

Once the robot is coupled with the tool, the next stage of the surgical workflow involves holding the target position while the surgeon drills and fastens the maxilla with screws and mini-plates.

During the laboratory experiments the LBR3 was subject to force applied by the surgeon to test its stability. Depending on the amount of force which was applied to the robot arm, the target position shifted almost 1.5mm. An overshoot upon release was also noted. The target position was recovered with positioning errors below 0.01mm, and orientation up to 0.06º. Also identified with the LBR3 is the axis stability difference.

Finally this study concludes that the LBR3 is adequate to handle this procedure. The loose maxilla can be held in position while the surgeon performs his tasks, and a force free intuitive coupling for medical robots is possible, pointing towards a method to be included in the development of new medical robots to achieve a safe, sterile, reliable and predictable design.

Further tests to assert the usability of this method should be made with actual patients. Additionally, there are still benefits to be achieved through the reduction in the overall size of the coupler and system.