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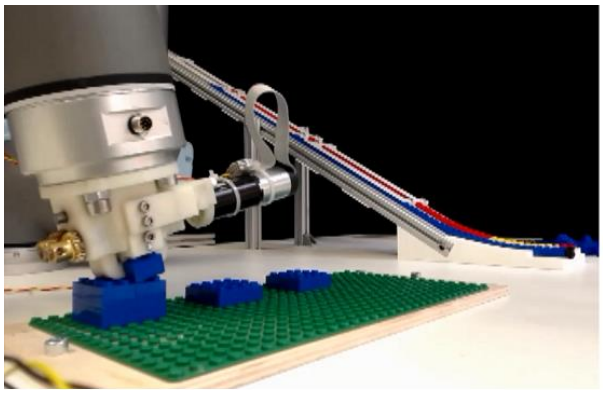
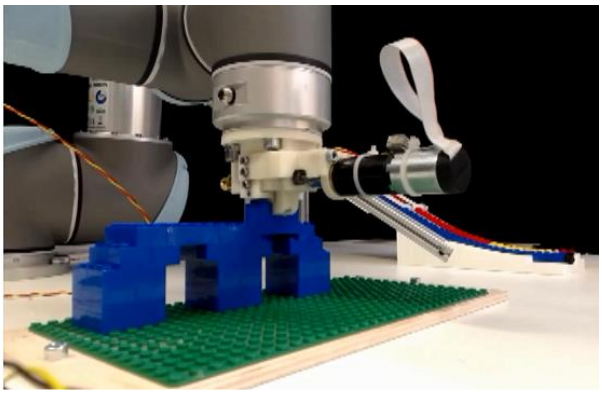
Online case study resource: Robotic Re-Fabrication of Lego Structures

My 4th year project takes knowledge acquired from multiple engineering areas to explore improvements in robotic manufacturing and robotics in construction. The project is split into 2 main tasks: developing the physical robot and exploring techniques to improve the performance of the robot. The final robot is able to assemble and dis-assemble Lego structures autonomously. This project is largely programming, all code for this project can be found at: https://github.com/kg398/lego_project. The project resources and demonstration videos can be found at: https://tinyurl.com/kg398-lego.



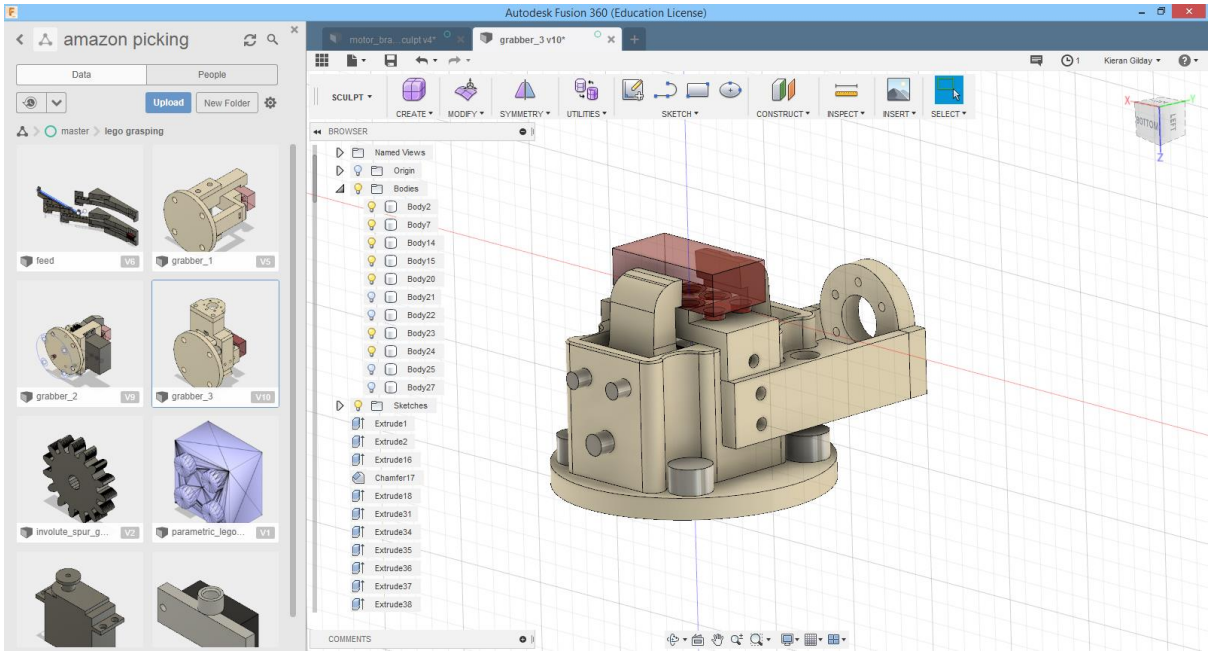


The first task involves:

- Learning to use the 'UR5' robot arm
- Designing and 3D printing a gripper and workspace compatible with the robot arm and Lego

The robot can be controlled by a computer using Python. The basics of python can be learned using free online tutorials. This code for this project avoids the more complex aspects of python. A basic set of commands has been created to control this particular robot. The simplest way to understand the robot control is to define the coordinate system, i.e. the x, y and z-axis, then tell the robot to go to a particular x, y, z location. Each joint of the robot can be set to a particular angle, using simple trigonometry, the position of each joint in this coordinate system can be found. This is the forward kinematics. The reverse of this, finding the joint angles required to reach a particular position is called the inverse kinematics. More complex control includes defining the orientation of the gripper, allowing twisting motions for separating bricks.

The gripper is designed using the CAD software 'Fusion 360'. This is free for students and offers similar performance to other leading CAD packages like Solidworks or Creo. 3D CAD is an incredibly powerful tool, however this comes with a steep learning curve. The user interface itself takes practice to operate smoothly. This is a requirement for 3D printing. 3D printing allows rapid prototyping and design iteration for these types of projects. Multiple designs were tested, with the final design using high quality motors and components to reliably pick and place hundreds of Lego bricks without failure.

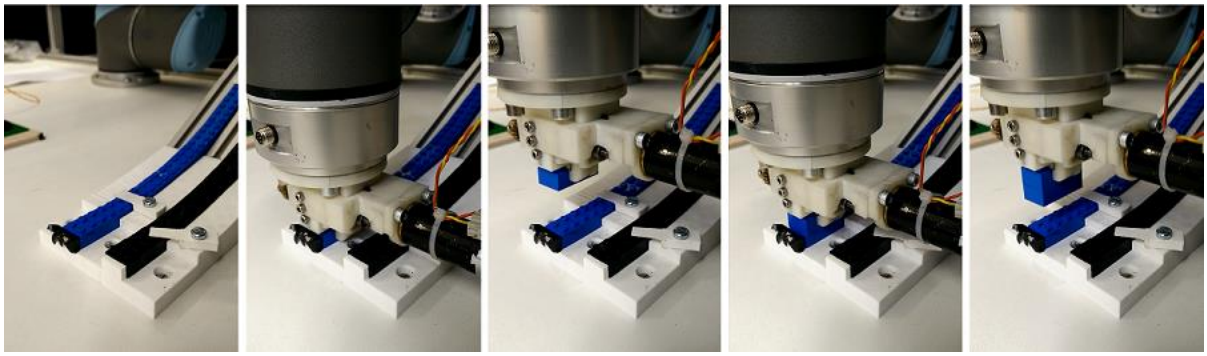


The second task involves:

- Automating the robot
- Developing intelligent algorithms and advanced construction techniques

The robot is automated by defining each potential task the robot has to perform. Then when the robot is given a structure to assemble or dis-assemble, the set of tasks required is easily found. The only thing remaining is deciding the best order to perform these tasks. Some tasks are more difficult than others and the order of tasks can make the job easier for the robot. The easiest way to determine the best order to perform the tasks is to simulate each potential order (each permutation) and pick the easiest. However, as the number of bricks increases, the number of permutations increases extremely rapidly so even a powerful computer will take a very long time to find the best solution. In this project this is solved by intelligently dividing the bricks into smaller lists which can be individually sorted and limiting the maximum amount of permutations to test.

The advanced construction techniques aim to improve the performance of the robot by either increasing the speed and reliability of the robot, or by increasing the range of tasks the robot can perform. By enabling dis-assembly, old structures can be recycled or transformed into new structures, saving time and resources for iterative design or prototyping. The best technique explored in this project is the use of prefabrication. The robot assembles a miniature structure or ‘tool’, then uses that to assemble or dis-assemble parts of the main structure it would be unable to otherwise. For example, the gripper design prevents placing bricks side-by-side, by picking up a stack of 2 bricks placing that stack then picking the top brick, this constraint is overcome, as shown in the double arch structure above.



The feed system can provide up to 2 types of bricks to the robot. The robot can store bricks in the feed system and even use it for simple prefabrication.

Overview

This project requires good 3D modelling and programming skills. These are introduced in most undergraduate engineering courses, however both require additional practice which can be easily performed with access to a computer. 3D printing is now much more accessible, with university resources, public ‘maker spaces’ or companies which print models for you. For someone interested in this type of project, I would definitely recommend getting an Arduino microcontroller, some small servo motors and access to a 3D printer and doing a small robotics project, such as a small walking robot or a simple robot arm.