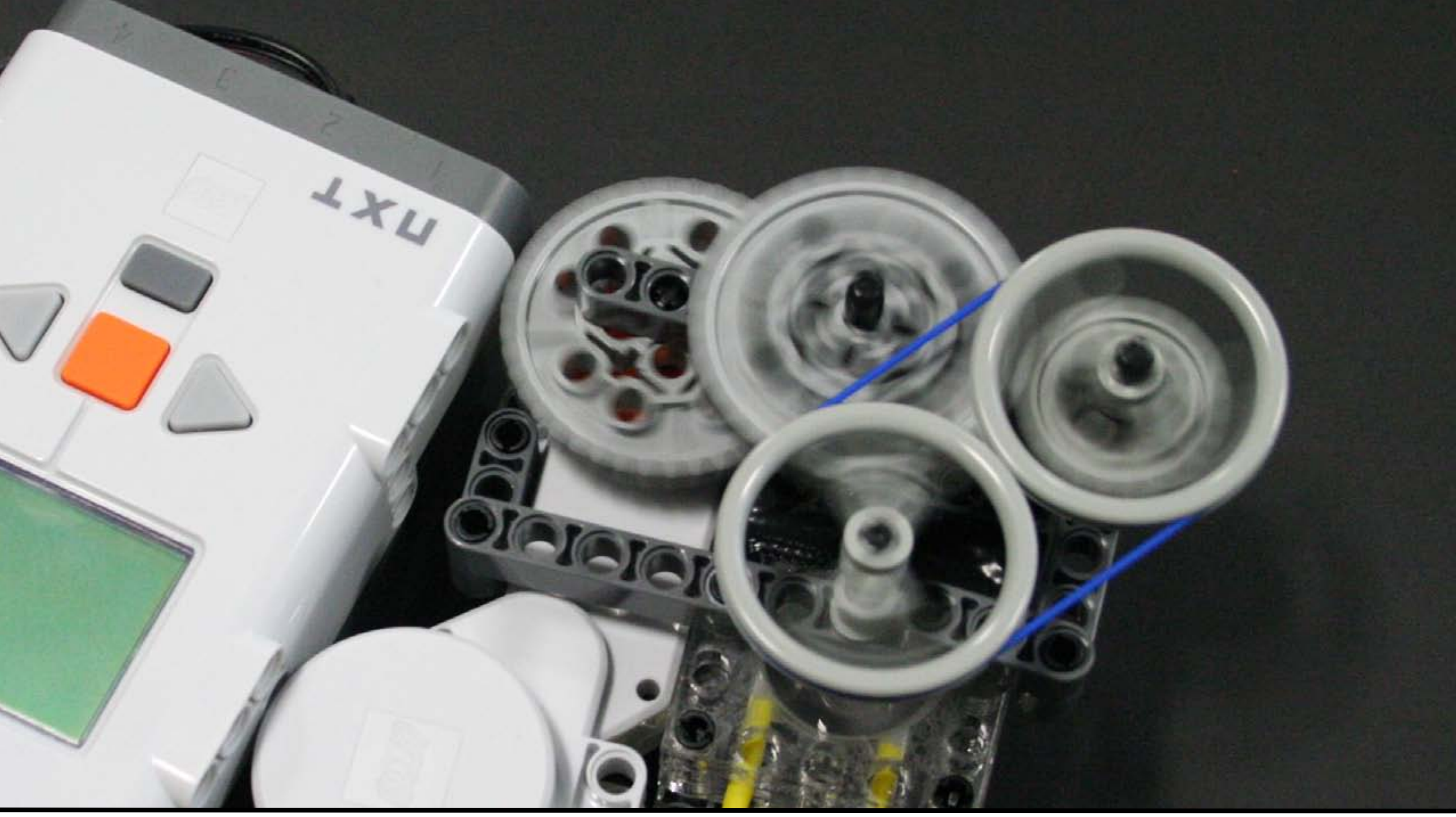

**DC403 - TECHNO CLASS**

# LEGO
## Beyond Toys

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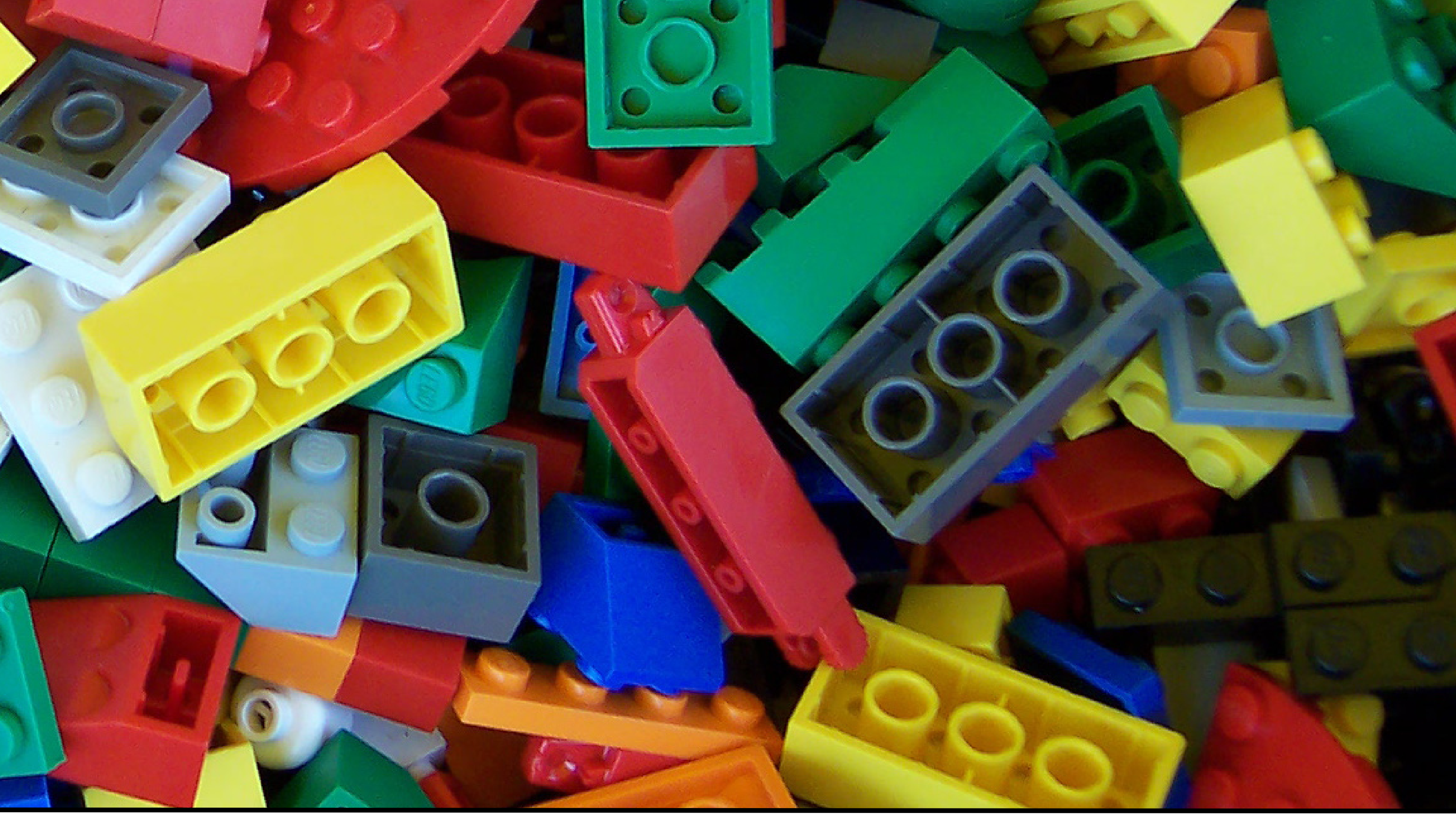


# 1. INTRODUCTION

This report will guide you through the process of creating a new extension pack for the LEGO Mindstorms system as part of the Techno Class, given during the Master study Industrial Design at the Eindhoven University of Technology. I will start by describing how and why I decided to build a particular brick. After that I will describe the process of developing my own extension for the LEGO Mindstorms system; a LEGO water pump. High quality video and images are available on request. Please contact me at t.a.m.v.bergen@student.tue.nl or through www.tomvanbergen.nl.

# 2. LEGO BRICK

## 2.1. Idea

The find inspiration for a new kind of LEGO brick I looked at different websites and forums. This also helped me to get a general understanding about what kind of things have already been done and where the opportunities are for developing something new. My first idea was to develop a rotary air motor that uses compressed air to create a rotary motion. These would be useful to replace the large pneumatic cylinders that are currently used for air operated systems. However, the advantage of the pneumatic cylinders is that they can provide a large linear force, something which can't be done as easily using a rotary air motor. My confidence in the usefulness of the rotary air engine began to fade. Then I found a video on YouTube in which someone used the pneumatic cylinders of the LEGO Technic set to push air in a bottle that was partly filled with water. The pressure inside forced the water out through a hose and in this way he was able to water plants using LEGO. It worked well, but is was kind of a difficult solution to the problem. What if you would have a LEGO water pump that could do the job directly? This idea really inspired me and made me think of other applications that you could create using a LEGO water pump:

- Fountains and water displays
- Plant watering systems
- Fire extinguishing systems
- Water jet propulsion
- Transportation of liquids
- Pressurizing of liquids
- Cooling

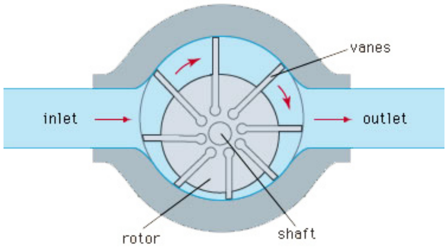
Obviously the idea had a lot of potential and since it has never been done before it seemed like a good opportunity to go and create a LEGO water pump that would add a whole new dimension to the LEGO system.

## 2.2. Pumps

There are many different kind of pumps available. Each one has its own specific characteristics and therefore its own specific advantages and disadvantages, making it possible to find a pump suited for a specific task. The most commonly used pumps are positive displacement pumps. They use a mechanism to repeatedly expand a cavity, allow fluids or gasses to flow in from a chamber, seal off the cavity, and exhaust it to the atmosphere. Some of the most commonly used ones are listed below.

*Rotary Vane Pump*
A rotary vane pump is a positive-displacement pump that consists of vanes mounted to a rotor that rotates inside of a cavity. In some cases these vanes can be variable length and/or tensioned to maintain contact with the walls as the pump rotates. While vane pumps can handle moderate viscosity liquids, they excel at handling low viscosity liquids. Vane pumps have no internal metal-to-metal contact and self-compensate for wear, enabling them to maintain peak performance on these non-lubricating liquids.

Vane pumps are noted for their dry priming, ease of maintenance, and good suction characteristics over the life of the pump. Each type of vane pump offers unique advantages. For example, external vane pumps can handle large solids. Flexible vane pumps, on the other hand, can only handle small solids but create good vacuum. Sliding vane pumps can run dry for short periods of time and handle small amounts of vapor. (www.pumpschool.com, Wikipedia)

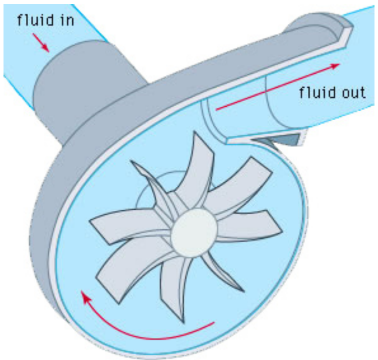


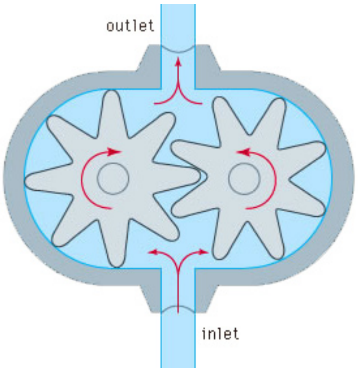

*Left: Vane Pump*

*Centrifugal Pump*
A centrifugal pump is a rotodynamic pump that uses a rotating impeller to increase the velocity of a fluid. Centrifugal pumps are commonly used to move liquids through a piping system. The fluid enters the pump impeller along or near to the rotating axis and is accelerated by the impeller, flowing radially outward into a diffuser.

A centrifugal pump works by the conversion of the rotational kinetic energy, typically from an electric motor or turbine, to an increased static fluid pressure. This action is described by Bernoulli's principle. The energy conversion results in an increased pressure on the downstream side of the pump, causing flow. (Wikipedia)

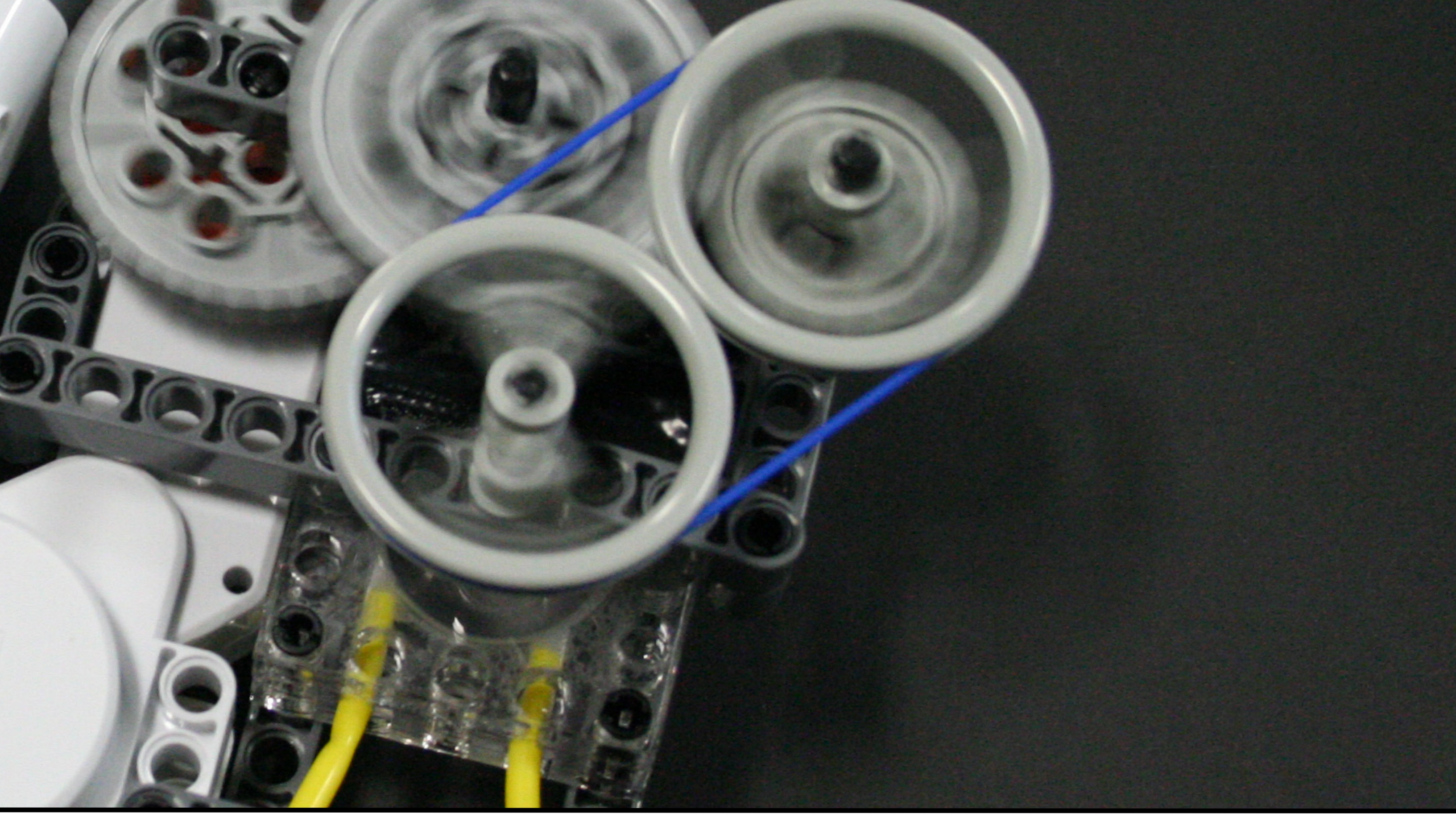
*External Gear Pump*
A gear pump uses the meshing of gears to pump fluid by a fixed displacement. External gear pumps are a popular pumping principle and are often used as lubrication pumps because of their simplicity, reliability, and very high power ratings. Small external gear pumps usually operate at 1750 or 3450 rpm and larger models operate at speeds up to 640 rpm. External gear pumps have close tolerances and shaft support on both sides of the gears. This allows them to run to pressures beyond 200 BAR, making them well suited for use in hydraulics. With four bearings in the liquid and tight tolerances, they are not well suited to handling abrasive or extreme high temperature applications. (www.pumpschool.com, Wikipedia)




*Top: Centrifugal Pump*
*Right: Gear Pump*

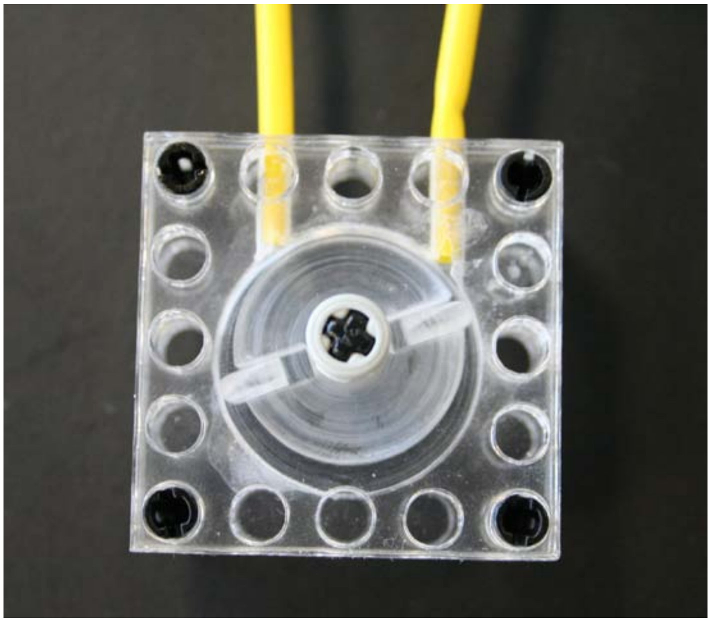
Obviously there are many more type of pumps available such as piston pumps, lobe pumps, scroll pumps, toepler pumps, wankel pumps and so on. I only addressed the most relevant ones in this chapter.

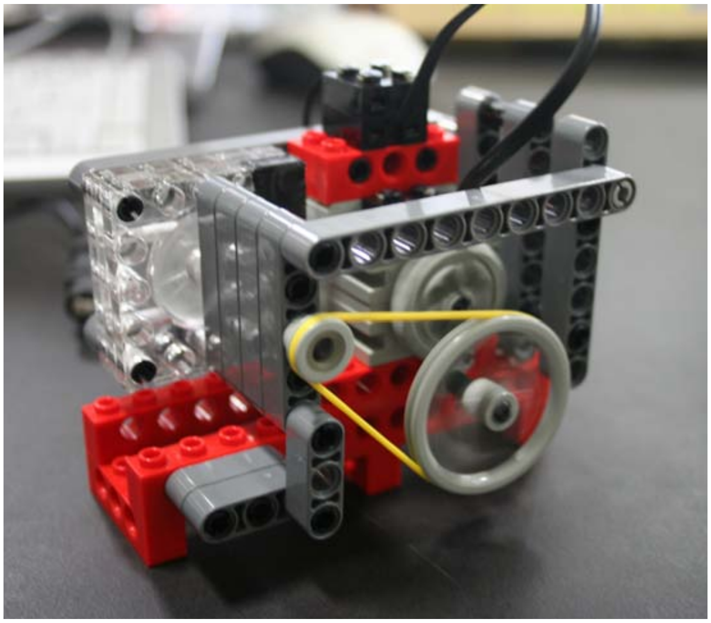


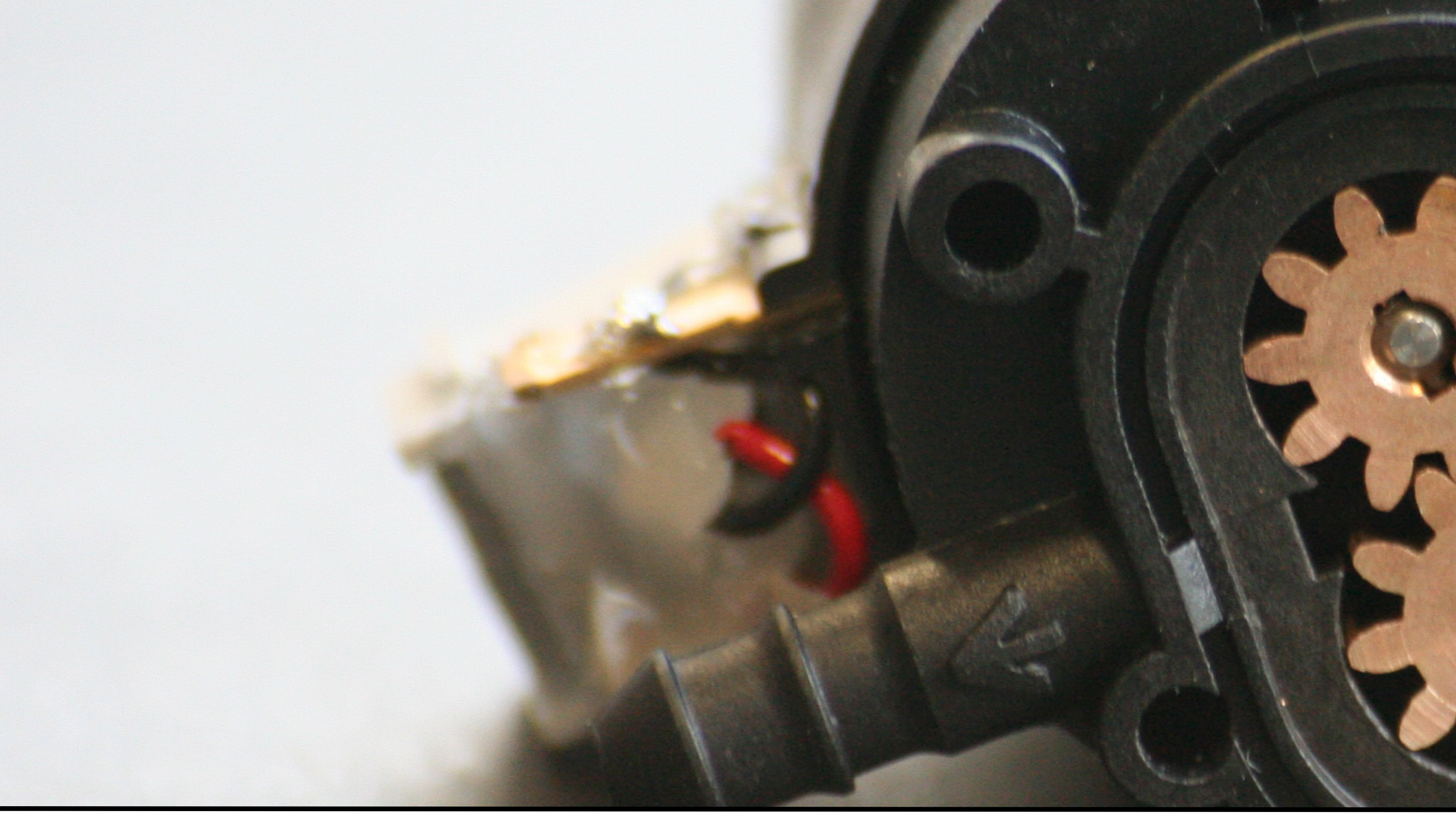
## 2.3. Development

I started to experiment with different kind of pumps to find the most suited one for my LEGO application(s). Initially I wanted to build my own vane pump because of its relatively simple design and good suction characteristics. I made the pump from laser cut Plexiglas so I could do some experiments with it.

The pump was powered by an external LEGO motor. Gears were used to increase the rotational speed of the pump. It turned out that the tolerances of my home made pump were not good enough as leaks between the individual parts meant that it could not suck in liquids and pump them around. Sealing was a real problem here and it would take a lot of work (and time) to get it on to an acceptable level of performance.

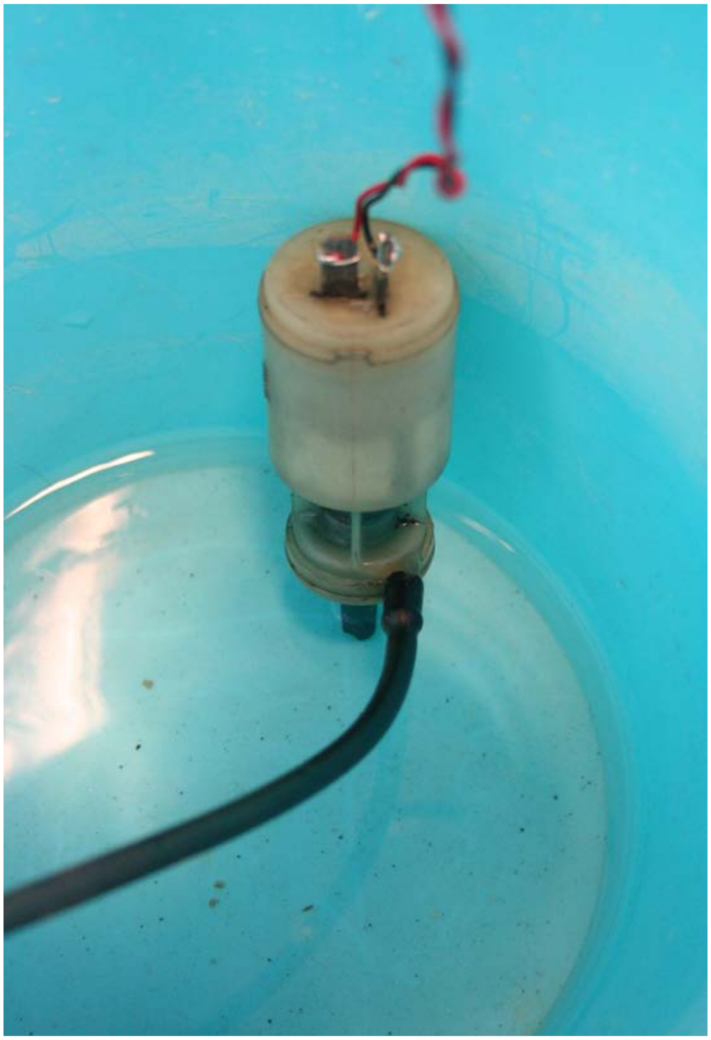




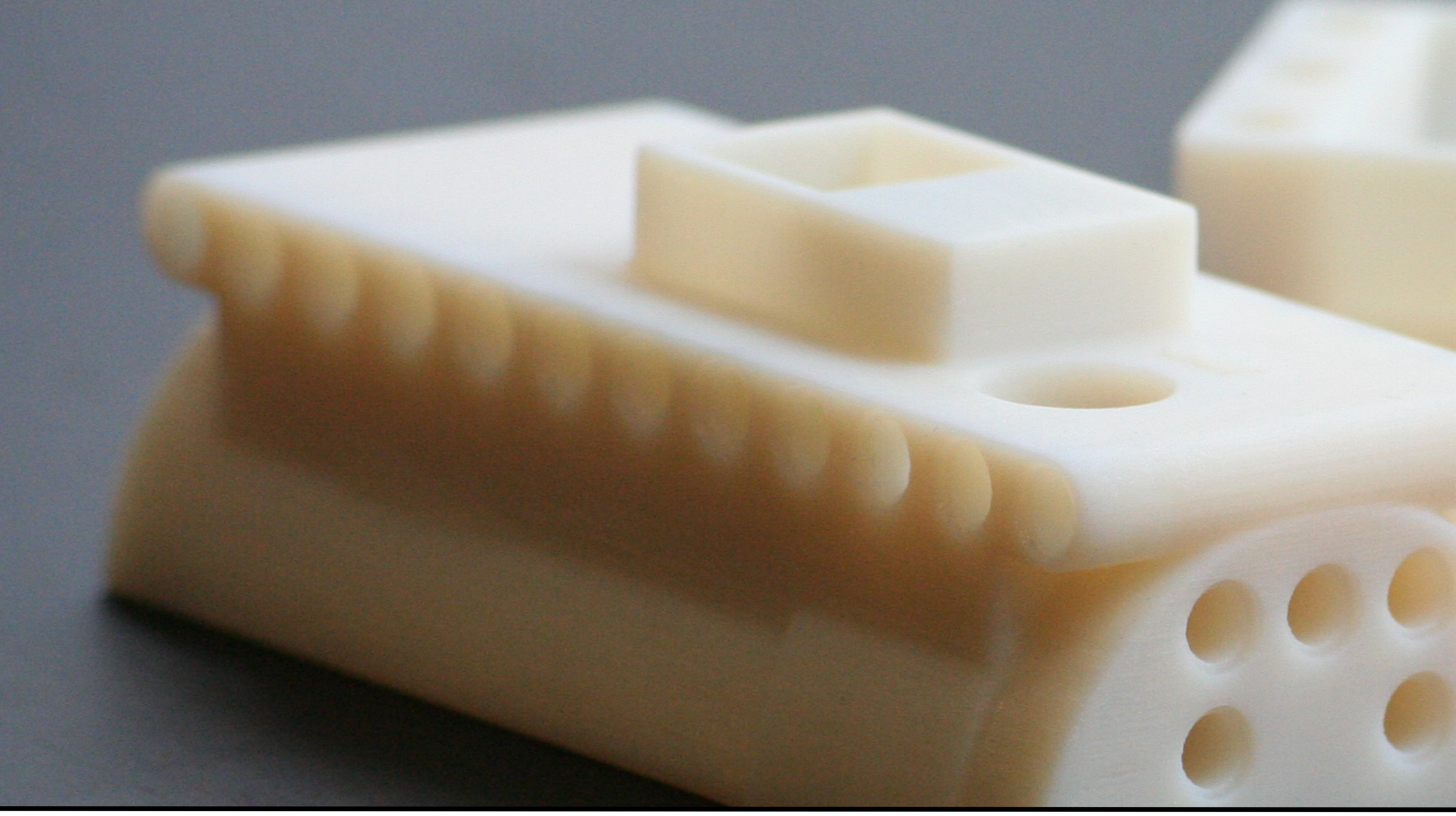


Therefore I decided to abandon the idea of making my own pump and use an already existing one instead.

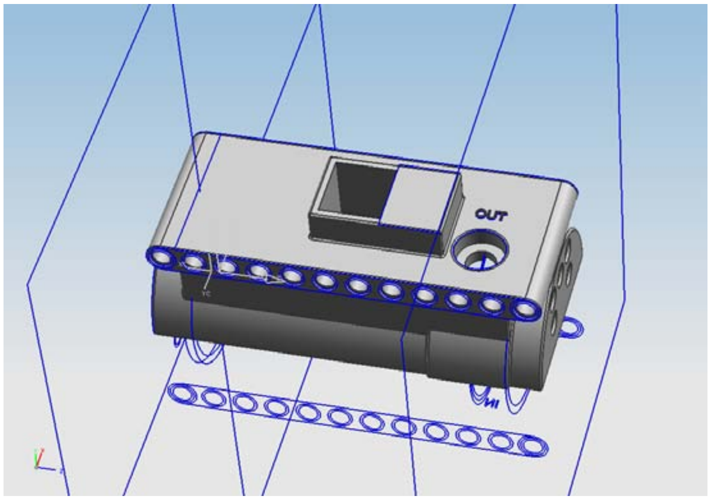
For my next experiment I used a windscreen sprayer motor from a car. This pump uses the principle of a centrifugal pump to force the liquid out at a high speed. The NXT was capable of powering this motor and it produced a reasonably strong jet of water (not as much as in a car because of the lower voltage and reduced amperage of the NXT). The downside of this pump was that it could not suck liquids in on its own (because it used a centrifugal pump principle). The bottom of the pump needed to be submerged in the liquid in order for it to work. Far from ideal for a LEGO application where you want to keep all the electronics away from liquids.

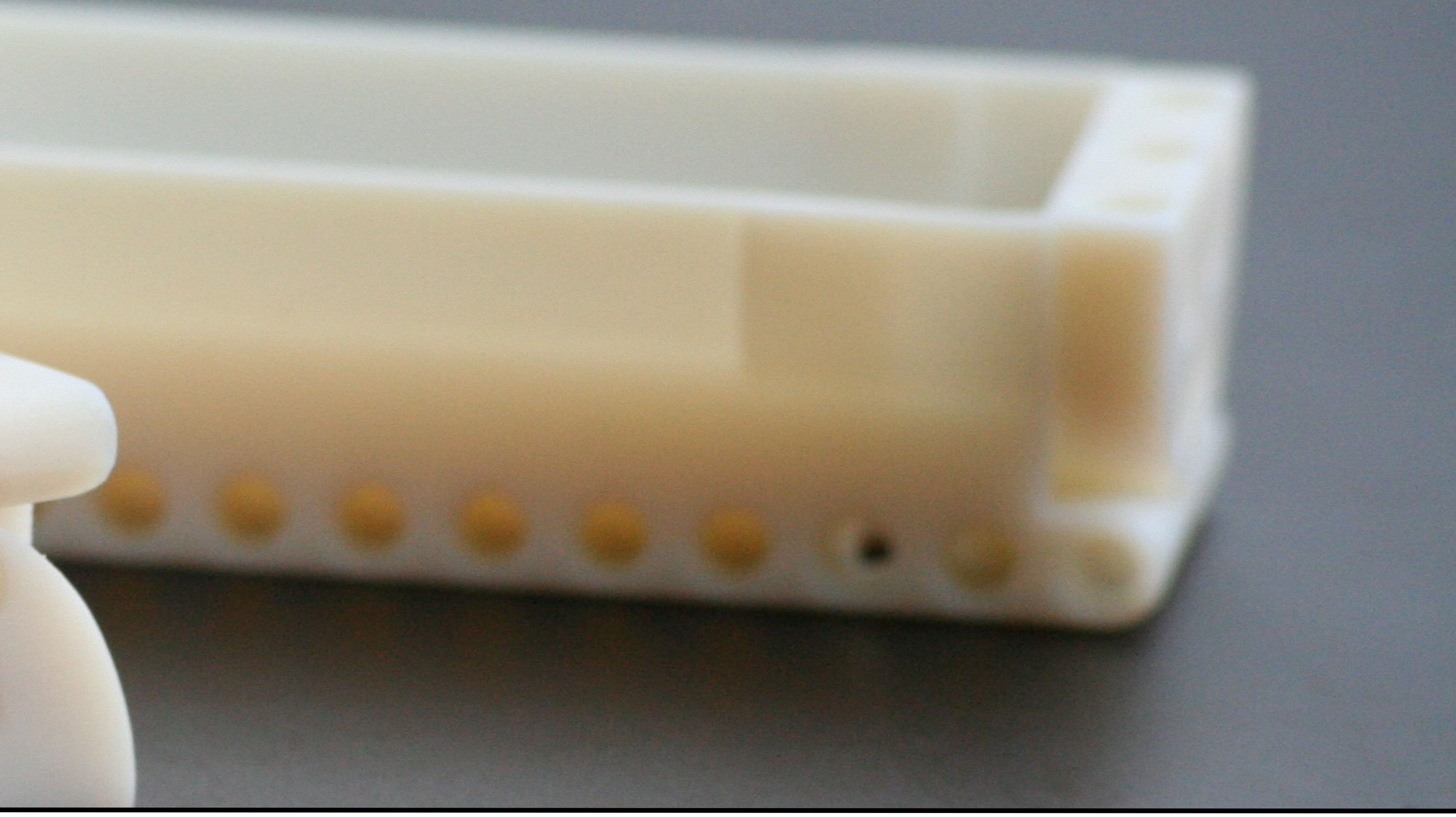


I went looking for another pump that was capable of creating a partial vacuum and thus suck in liquids on its own. I found a small, universal gear pump on the internet that was perfectly suited for my application. It has few internal components and has the right size and power supply for the NXT. It also flows enough liquid and builds enough pressure for LEGO relevant applications and it can suck liquids in from a large distance. Besides that it is also the cheapest type of pump available. It works using the gear pump principle as described in the previous chapter. The pump is manufactured by Kavan (nr. 0190) and rated at 12 Volt and 1,5 Ampere, flowing up to 1,8 liters per minute. The original dimensions are 73 x 46 x 60 mm. The brass gears ensure a long life and allow the pump to run forwards and backwards. The main challenge now was to make the pump fit within the LEGO system by adding connection points and make it controllable directly by the NXT.



To make the casing for the pump I took all the required measurements and modeled a 3D CAD model of the casing. I made sure enough mounting points would be available for other LEGO components to connect to, both on the top/bottom and on the sides while keeping the shape as small as possible. Because of the odd shape of the pump with all the different bits sticking out of it, I could not make a single casing with a lit to close it. Instead I decided to make two halves that would fit over the pump and meet in the middle. To connect the two halves I did not create my own snaps or other connection points, but instead I used the LEGO itself to connect the two halves and make a solid and strong casing for the pump. The nozzles for the water stick out of the casing so different hoses can be connected and because the original in-out markings were now inside the casing I added small markings on the casing to indicate which nozzle is input and which is output (although the pump can also work in reverse). Also some minor adjustments had to be made to the cover plate of the gears to reduce the size of the casing.



Once the model was finished it was send to a 3D rapid prototyping (SLS) machine where the two halves were build up layer by layer. They snapped together perfectly using the standard LEGO connection pins, fixating the motor solidly in between. The in and output nozzles stick out far enough to connect different hoses. It was painted a dark LEGO gray so it looks like a real LEGO brick.

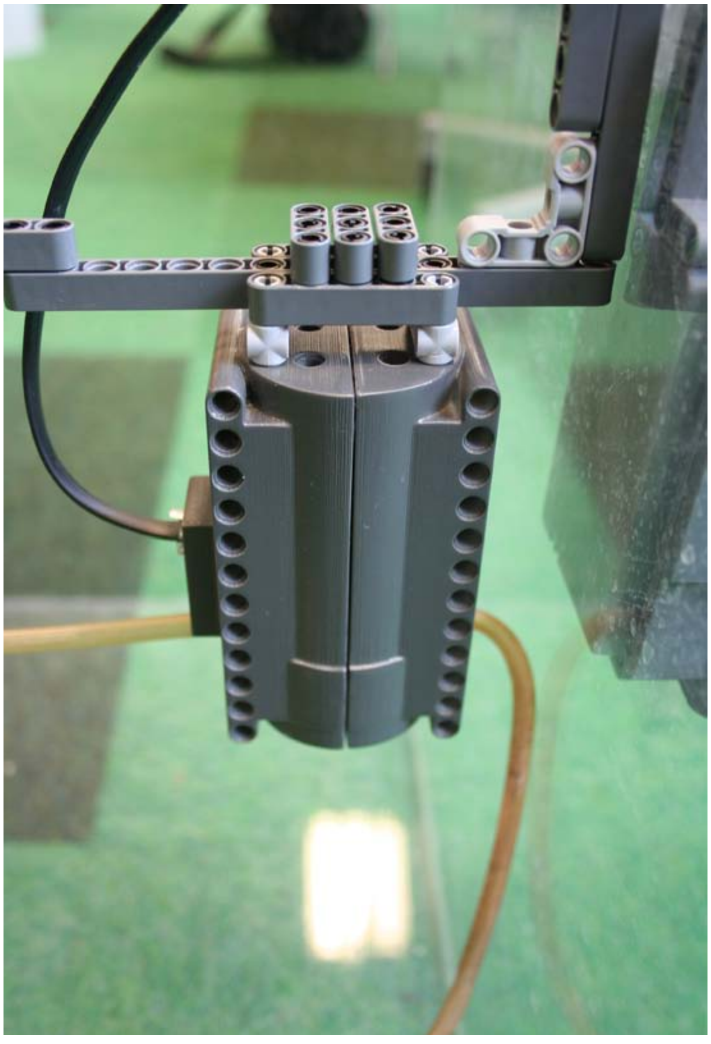
As far as the electronics go, the two electronic connection points (positive and negative DC poles) were soldered directly to an NXT plug from Mindsensors, allowing the pump to be run forwards and backwards using PWM signals. The pump can be controlled in the same way you would normally use an old fashion DC LEGO motor. For example the output of the pump can be directly controlled by an ultrasonic sensor as you can see in the example LeJOS JAVA code on the right. The minimum output should be kept around 40 or 50 % to prevent stalling.

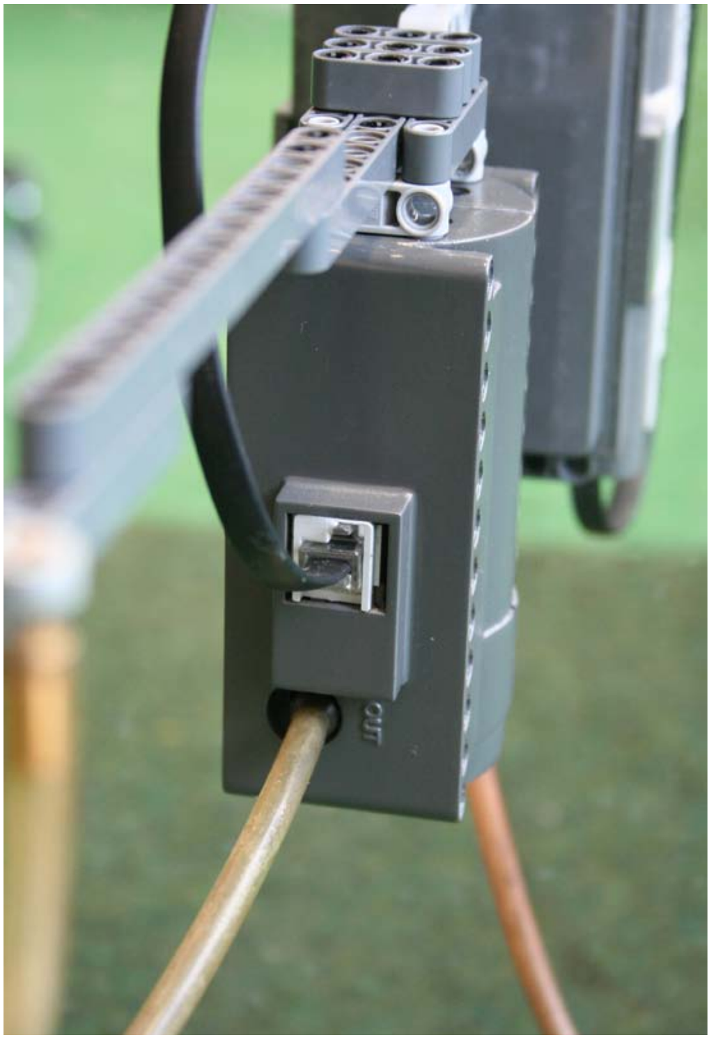
```
import lejos.nxt.*;

public class Pump{

static int power2;

public static void main(String[] args){

    UltrasonicSensor sonic = new
    UltrasonicSensor(SensorPort.S1);

    while (true) {
          double power = 100 - ((sonic.
          getDistance()));
          if (power > 50){
                power2 = (int) power;
          }
          else{
                power2 = 50;
          }
          Motor.A.setPower(power2);
          Motor.A.forward();
    }
}
}
```

## 2.4. Final Brick

The final brick was placed in a test setup to see if it was possible to connect it to the existing LEGO system and create an interesting application with it. To show the potential of the pump an interactive fountain was created. The power of the pump and thus the height of the fountain are controlled directly by an ultrasonic sensor as described in the previous chapter. The fountain is placed in a Plexiglas container holding a few centimeter of water. The pump sucks water from the bottom of the container and then sprays it into the air from the center of the container. The water then falls back in the container where it can be reused. The pump works consistently as long as it has a constant supply of water on the intake side. A benchmark test with the NXT showed it could flow around 0,9 liter per minute at full power. The pump works most efficiently if it is placed with the in and output on the bottom like on the pictures. As said before, the minimum power should be kept at around 40 or 50 % to prevent stalling. If the pump does stall it needs to be turned off completely in order for it to start up again. The shorter the in and output hoses, the more efficient the pump can work as the water encounters less resistance if it travels through a shorter hose. If the water is forced through a narrower hose or opening it will force the water out at higher velocity. This principle was used in the fountain to make it spray the water higher in the air. The brick is not watertight, however because the original pump is already enclosed in its own casing it can withstand a sufficient amount of water penetration. The electronics are also very simple with a reasonable distance between the wires, making it hard to short circuit. A few drops don't hurt, but the pump should not be submerged in water and kept as dry as possible to prevent damage. Technical drawings can be found on page 15 and 16. Different kinds of fluids can be used but this has not been tested. An additional product can be an external gear pump without an attached electromotor. The package can be reduced in size and costs and users will have to use their own motor and create their own gearing in order to make it work.

A lot of different applications can be created with the water pump as described in chapter 2.1. It is up to the LEGO community to discover new applications and apply it in new and innovative ways.

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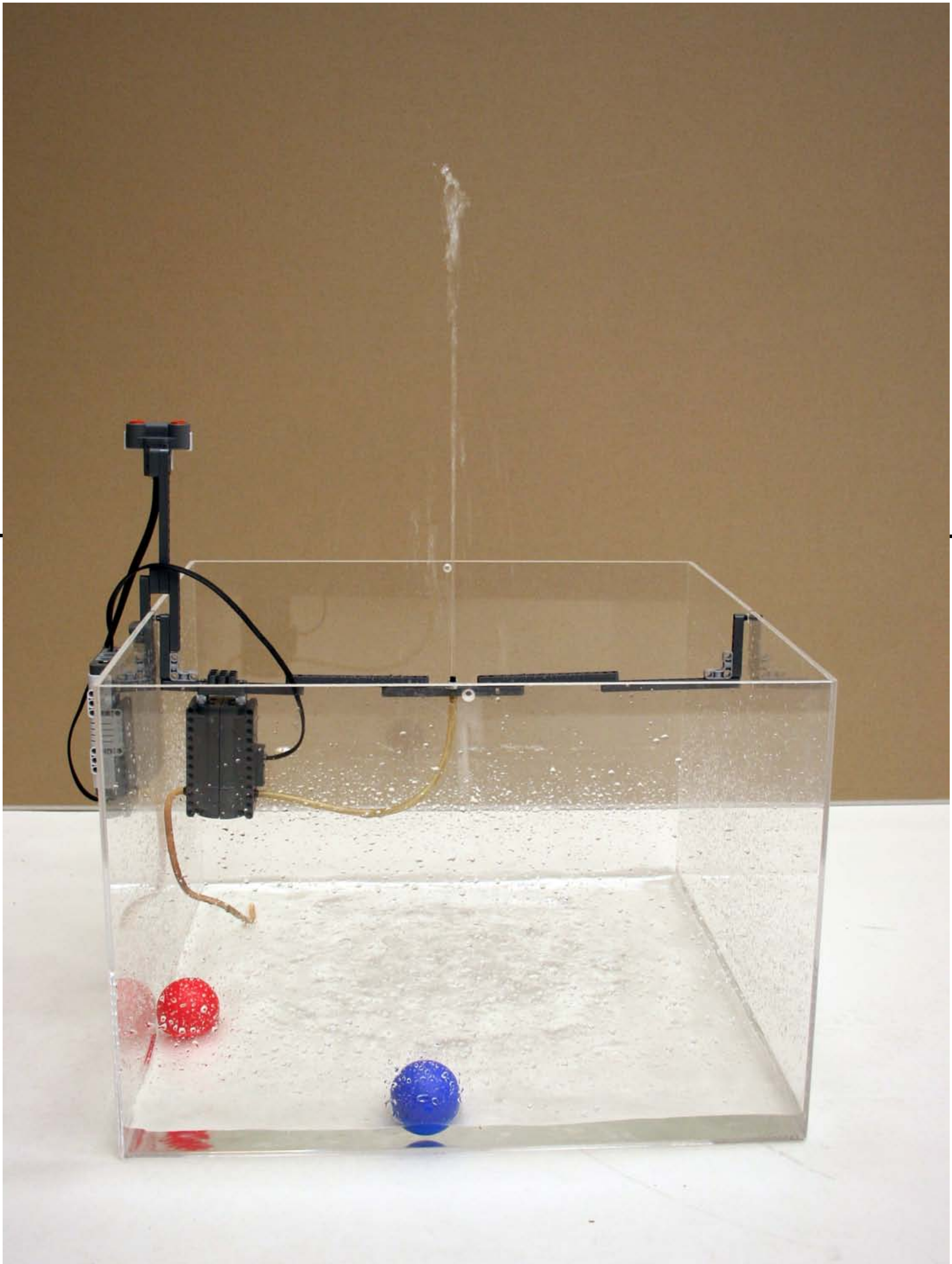

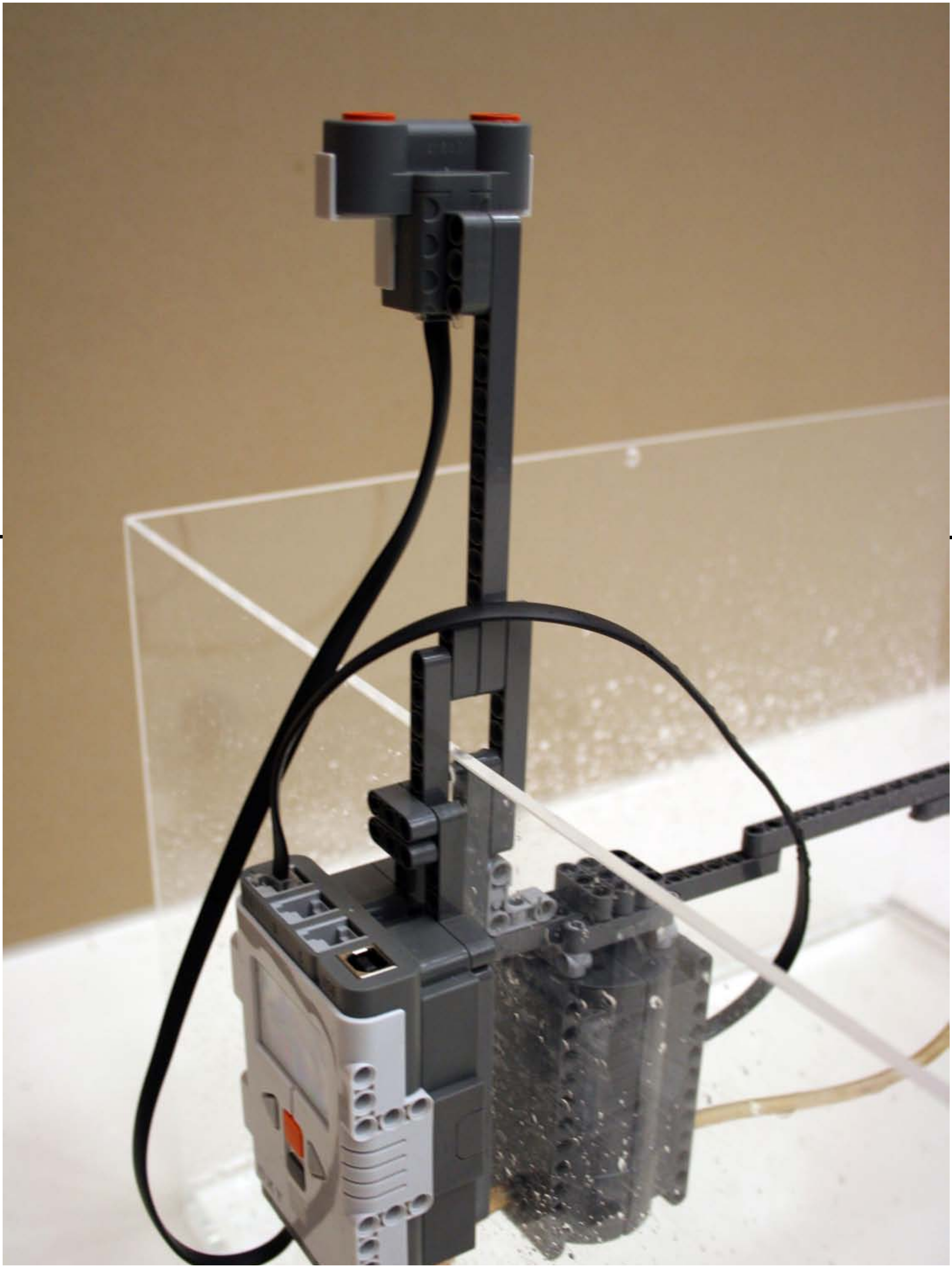

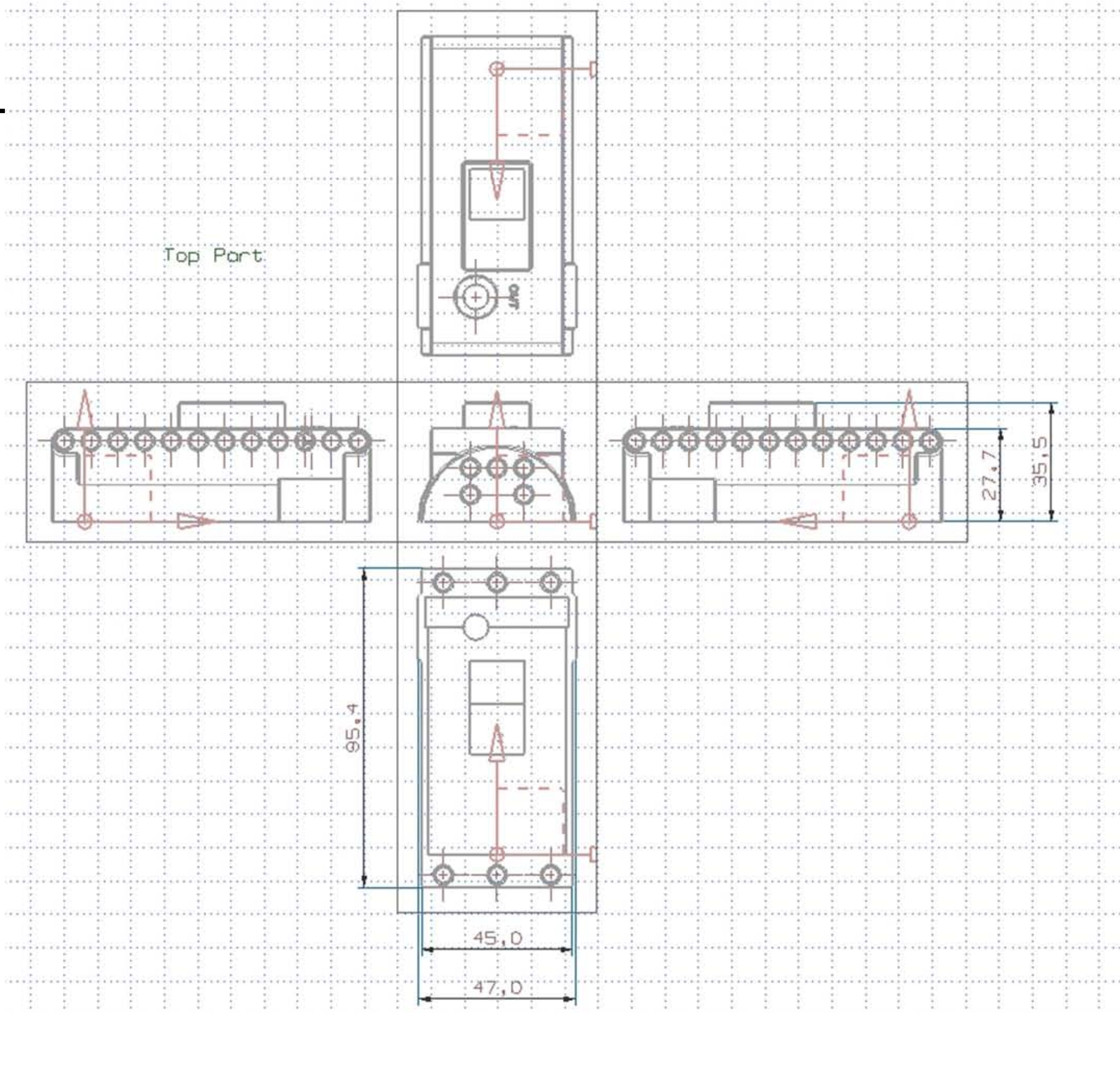
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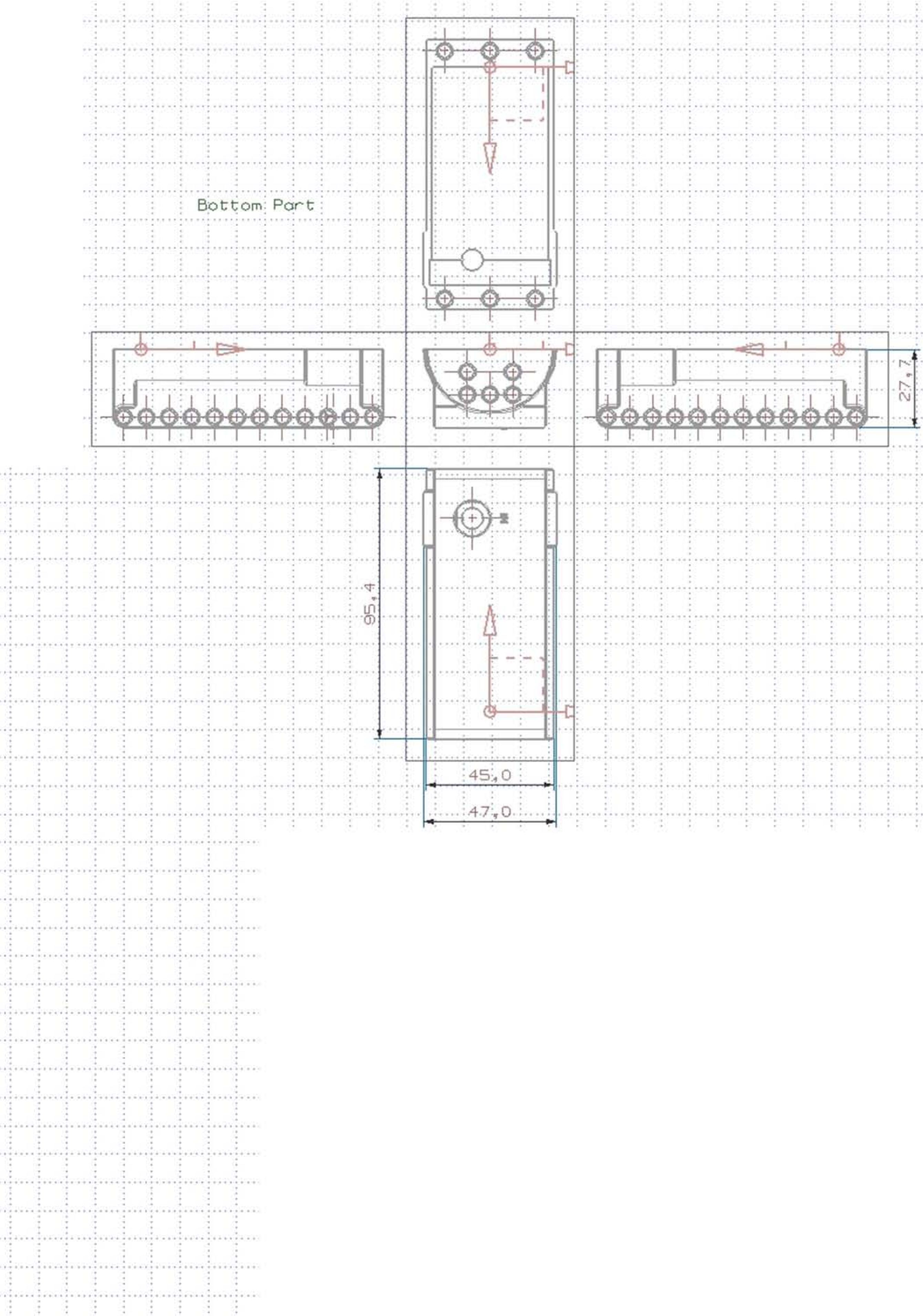
27,7
95,4
45,0
47,0


Bottom Part
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