Undergraduate Research Paper

Design Elaboration of a Mechanical Torso for SAFFiR Robot

Written by: Sebastien Corner

Torso Team Design Members: Sebastien Corner, David Henry

Advisors: Dr. Dennis Hong, Derek Lahr.

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Abstract

The purpose of this research is to develop a lightweight and robust humanoid robotic torso for the SAFFiR Graduate team that can throw a 1.2 kg mass at a distance of 9.2 m. The graduate team has been charged with developing a humanoid robot that can assist with the fire suppressing activities aboard a naval vessel. The graduate students have designed a set of humanoid legs and have started testing the walking algorithms. They are in need of a torso that can perform the fire suppressant tasks which include throwing a peat canister and manipulating a fire extinguisher. Both of these tasks present difficult challenges for robotic locomotion and this research project's goal is to design and then manufacture a torso that can accomplish those goals.

In charge of this project is David Henry, a senior student paid 20 hours per week to work on this project, assisted with Sebastien Corner, a senior student whose torso project contributes on his undergraduate research.

The engineering design methodology is being followed to uncover the best possible design for the torso. Tools such as simmechanics and NX are being used to assist the design phase. The main design has been completed and plans are to have a working prototype manufactured by the 1st of June 2012. This project was done with the collaboration of ROBOTIS, a robotic company in South Korea, who is in charge of developing the arms of the SAFFiR robot.

Costumer Needs and specification

The identification of the customer needs and specifications is the crucial part of the project. Each of them represents a boundary of the design used by engineers to elaborate a final product. Designing a product can be represented as a box, which is randomly surrounding by specific boundaries. Then with time and analysis, this box is transformed to a perfect form that shapes and matches all these boundaries together.

It is inside this ideology that we defined all the needs for the torso design. First we determined the dimension of the tors. Knowing that SAFFiR should not be taller than 1.50 m and the actual robot height is about 1.15m, the torso plus the head and the neck should be around 35 cm. The shoulders should be width enough to avoid any interference with any component of the body.

The weight of the robot is a crucial point for the graduate students. The heaver the robot is, the more power that will be drawn from the actuators. Thus, it was required to limit the overall torso designed to 10 kg. This includes any sensors or computers installed on the torso.

The design should include several degrees of freedom. A Yaw joint is required for the torso to assist the throwing motion of the peat canister and a Roll may be included too. A study of the benefits of having a Roll joint was explored. Like humans, the shoulders need three rotational degrees of freedom. The elbows and the wrist need one and two rotational degrees of freedom respectively. The neck and head are required to have a Roll and a Pitch joint. The combination of these joints should enable the camera, set on the head, to look over the range of angle of 180° from left to right and from bottom to top. This will allow the robots to see its feet.

The main mission of the SAFFiR robot is to suppress a fire. To accomplish this task the robot will throw a peat canister. This will be the most demanding task the torso will need to complete and it can be clarified to throwing a 1.2 kg peat canister to a distance of 9.2 meters.

To explore its environment or identify its own position in a room, SAFFiR will use numerous of sensors such as cameras, Lidar, sonars, radars, and UV sensors. The detail of these sensors is unknown and dependent on an outside lab. Therefore, the torso design should incorporate brackets for all the sensors and define their specific locations on the torso or head.

When designing a humanoid robot, it is important that it looks like human. This robot will have to walk on a naval ship which is made especially for humans. Therefore to avoid any obstacle such as a door or a scale, the robot should relate its dimension to an human body. For that, information from the 50 % man data is used. This data gathers and averages all corporal dimensions from 50 % of the world population. Thus, the height of the torso needs to be around 20 cm for head and neck.

Robotis specification

Robotis is a company specialized in robotic motors that have the advantage to be really powerful and light. It is because of their world leadership in this domain that Robotis is the main RoMela partner. It is within this partnership that Robotis was given the responsibility of making the arms for SAFFiR according to detailed specification provided by the torso team. The specification includes all the arms dimension related to the 50 % data man, the required shoulder torque and the canister initial velocity. All detailed information can be found in the report " Arm Specification". Figure 1 shows a detailed sketch used to determine the initial velocity required to throw the canister at 9.2m. It is expected that a release velocity of 9.6 m/s and a release angle of 40 degrees is needed to propel the canister.

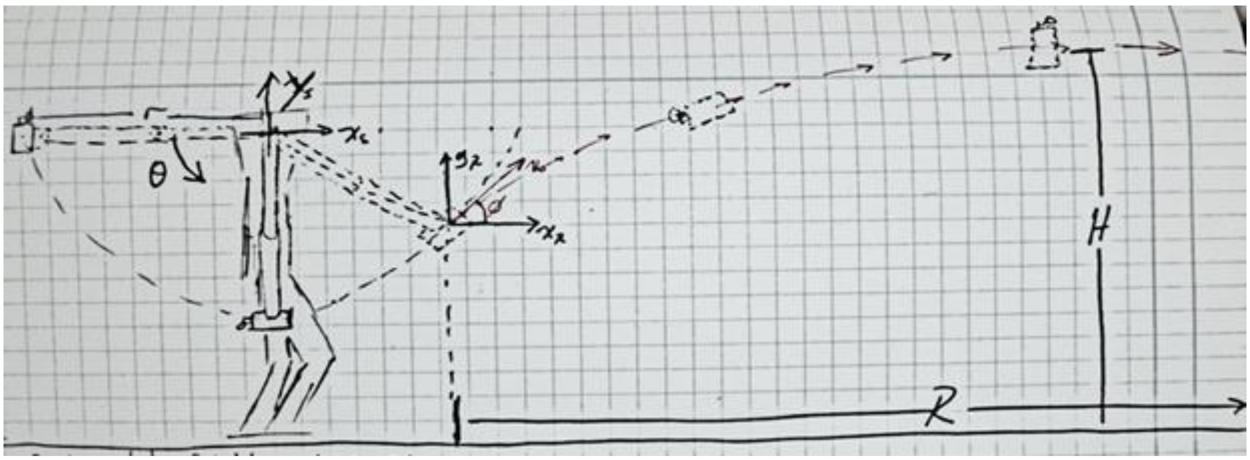


Figure 1. Schematic of Simple Pendulum throw and initial expected flight path.

After defining the boundaries of the torso design, we explored any possible ideas and choose the best design that will match all these boundaries together.

Simulation

One of the main challenges of the design was to explore the benefits of using a Yaw and a Roll joint in the throwing motion. For that, we decided to make a simulation of the torso using Matlab / SimMechanics. SimMechanics is a wonderful tool based on joint and body connections. In short, the user creates mass bodies by defining their respective mass, inertia and dimensions. Then, the user connects bodies with joints of desired degrees of freedom. The torso is simulated as a rectangle with two vertical and horizontal bodies connected by rotational joints. The torso rotates related to a fixed base thanks to a Yaw joint. The arms are attached to the torso and work as two simple pendulums that freely swing.

The first simulation explores the benefits of using the Yaw joint in the throwing motion (figure 2a). The rotating Yaw joint is controlled by a PID controller that tracks a given angular input data. We command the angle to reach 60 degrees backward in 0.3 s, remain at this angle until 0.5 s and then moves to the opposite direction to 60 degrees, reached at 1.3s (graph of the angle is presented in figure a1 in appendix). The simulation shows that having for the torso a Yaw joint leads the free arms to swing and speed up the canister velocity set at the right hand.

The velocity of the canister thanks to the Yaw joint and to this particular input data leads to obtain an initial velocity for the canister when throwing to 2,25 m/s, which represents 25% of the required velocity (9.6m/s). Thus the Yaw joint really benefits the throwing motion.

The second simulation involves a Roll joint in the torso base. In more details, the rectangle torso shift to the right or the left to form a parallelogram with desired angle (figure 2b). This angle is controlled by a PID controller in which we set an input angle of 20 degrees that moves the torso to the right. This simulation shows that the motion is similar to the previous one. The difference is that it gives to the torso more flexibility that makes it looks like an human.

Advantage of this innovative mechanism is it shifts the center of gravity of the torso to the right or to the left which can be beneficial for the robot when walking. This solution is really helpful when it is desired for the robot to have short shoulders. The moment of the canister according to Yaw axis is raised that leads to increase the canister's velocity. But this advantage is insignificant for width shoulders. The distance added when shifting is too small to be considerate. One of the main disadvantage of this mechanism is it increases the Yaw torque, thus more power may be required from the motor.

With a factor of safety of 2, results of both simulations determine that a power of 35 Watt is required to move the torso according to all specifications detailed in this section. The left and right Torso will require a bit of more power in average value. Detailed results of this simulation can be found in the appendix.

Future work of the simulation will be to match, with more precision, the inertia and weight of the real torso with the characteristics of each body that composes the simulation design. The goal will be to use this simulation in order to control the real Torso and thus determine the correct acceleration and rotational velocity angle required to throw the peat canister. The arms in this simulation were not controlled, so they were free to move. The next step, will be to control them in order to throw the canister to the correct initial velocity. One main issue of this task will be to coordinate the Yaw torque of the torso with the torque of the motors in the shoulder in order to obtain an efficient swinging motion of the arms. We note that the shoulder has three motors, one for each degree of freedom, thus, increase the level of complexity of the control.

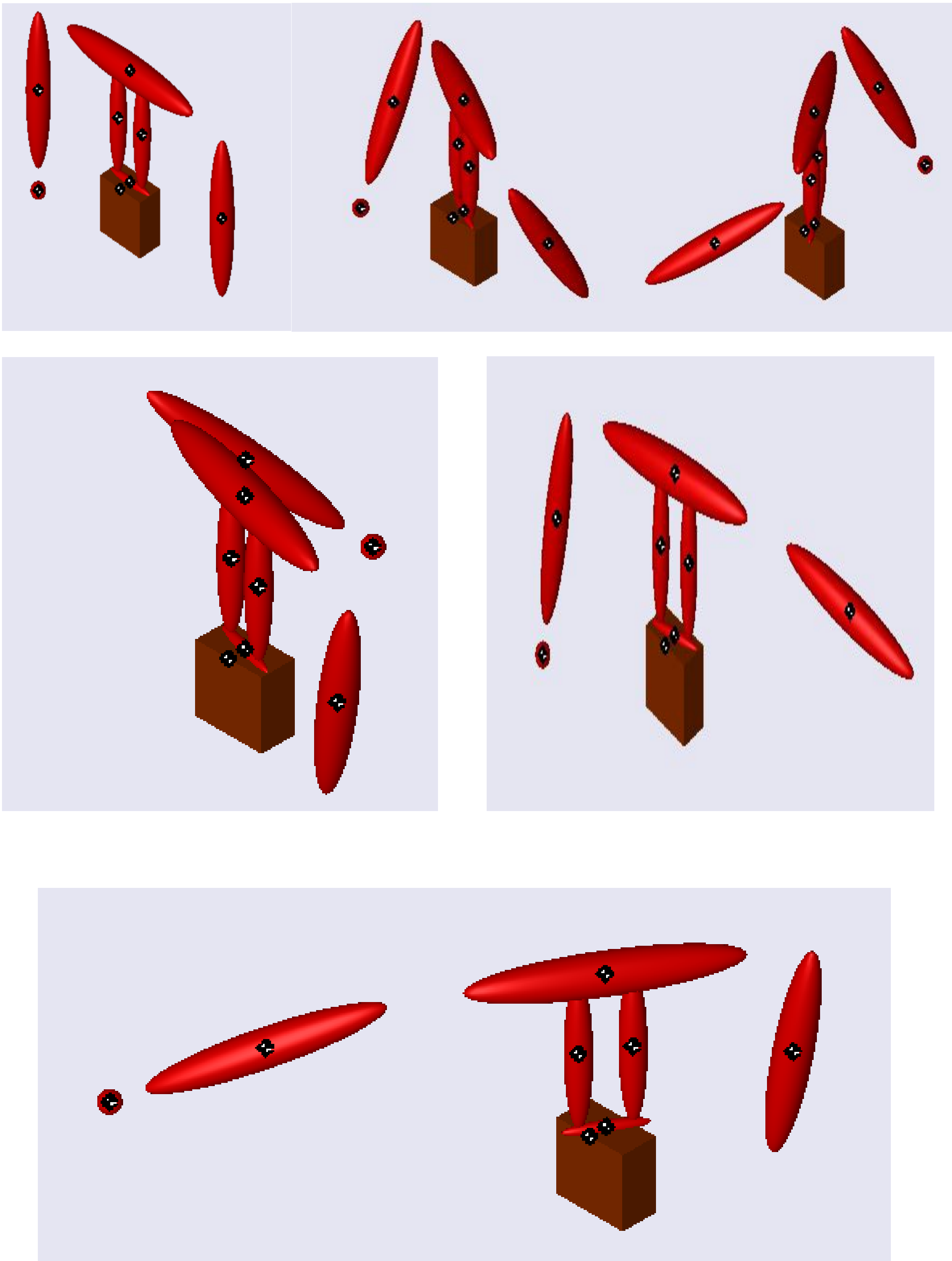


Figure 2b. Simulation of the Torso that includes both a yaw joint and a left and right motion. The first and last pictures were taken at t=0s and t=1.4s respectively. he canister is represented by a ball situated at the right hand.

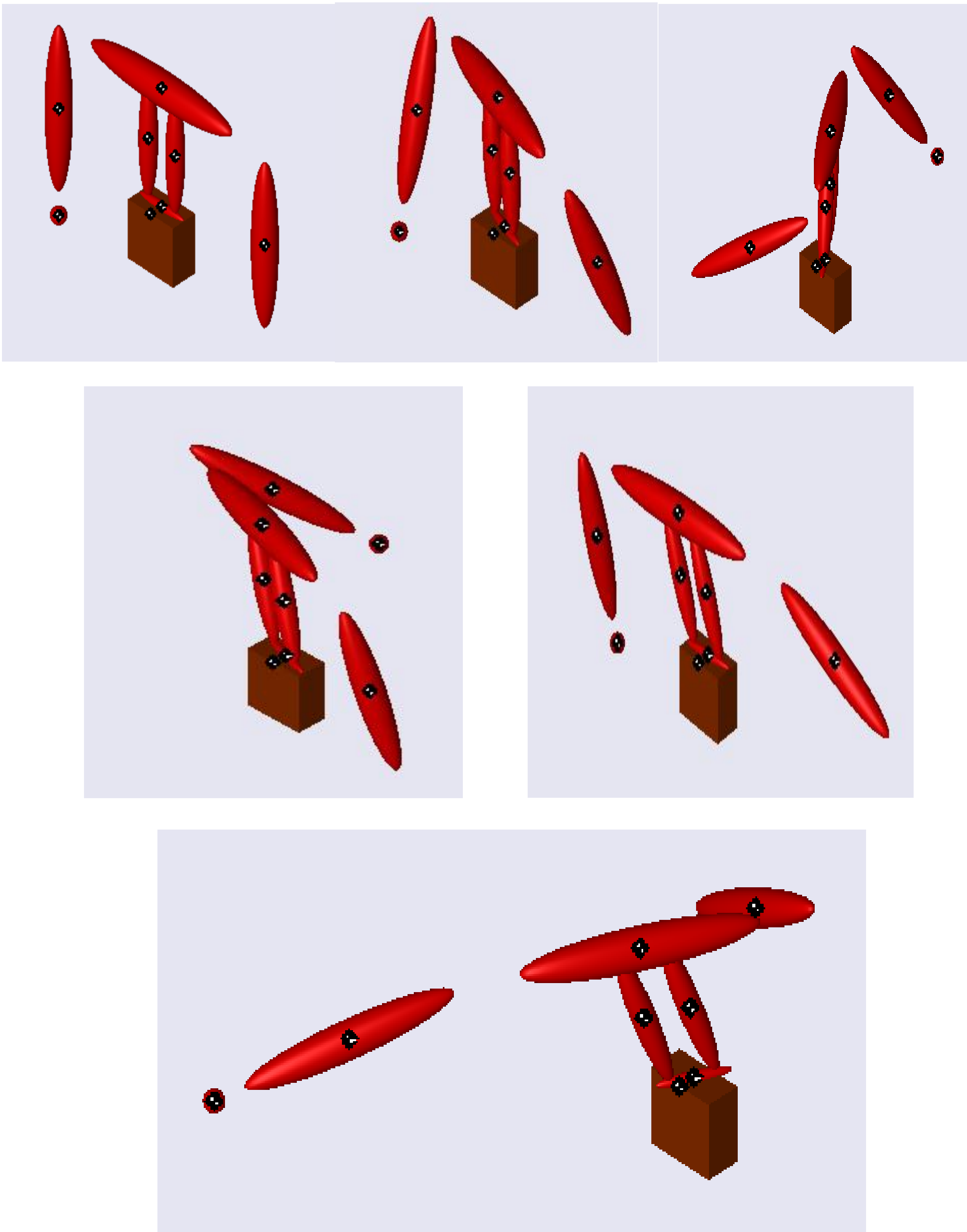


Figure 2a. Simulation of the Torso that includes only a yaw joint. The first and last pictures were taken at t=0s and t=1.4s respectively. The canister is represented by a ball situated at the right hand.

Prototype and sketches

In parallel of the simulation task, the team generated prototype and sketches of concepts explained on the simulation. Figure 3 shows a picture of the left and right prototype that works remarkably well. The rope is fixed on the two shoulders and rotates on the pulley located at the bottom. A joint rotation is set on one of this pulley than enables to rotate the rope and thus moves the shoulder to the left or right. Since the distance of the rope change when rotating, we added a spring between the fixed point on the shoulder and the rope that tracked the required distance of the rope when rotating the spines.

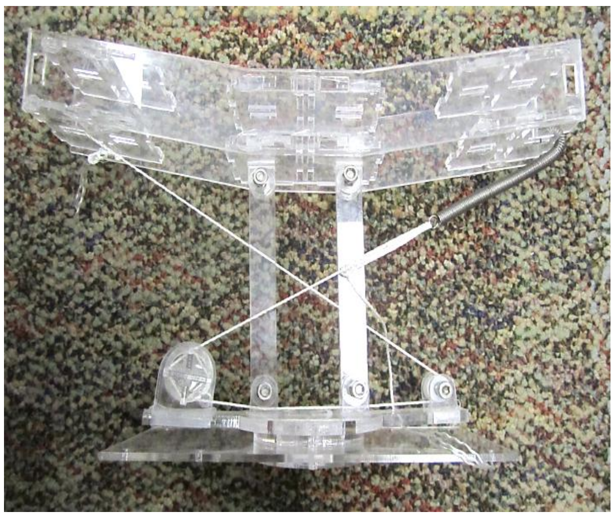


Figure 3. Left and right prototype. The mechanism is activated when rotating the joint on the bottom left.

The second concept was a multi degrees of freedom spine presented on figure 4 (no simulation was done on this concept). The human spine is made of small vertebrae connected by small tendon and muscle that enables our body to have numerous flexibilities. The idea was to reproduce this flexibility by connecting multitude of small plastics pieces by rotational joint. Then, thin cables are used to activate these joints that enable the spine to twist itself to numerous ways. The result is really impressive but this concept was not pursued for the torso because it will be really difficult to control it and the mechanism is not really stable.

Figure 4. Multi degrees of freedom spine. Each plastic pieces are connected by rotational joints.

The last concept is the yaw rotation torso design as explored on the simulation. A sketch of this design is presented in figure 5. This design does not include any Roll rotation or any movable spine which leads the torso to be obviously much simpler. It incorporates at the row joint the same motor than the one in the shoulder. This motor has the advantage to be really powerful, 50 Nm and 120 rad/s. The motors also incorporates numerous thread holes in which fixture can be set on the motors. Thus, the design is made of two identical side plates that set on the three motors and thus leads the overall design to be really strength.

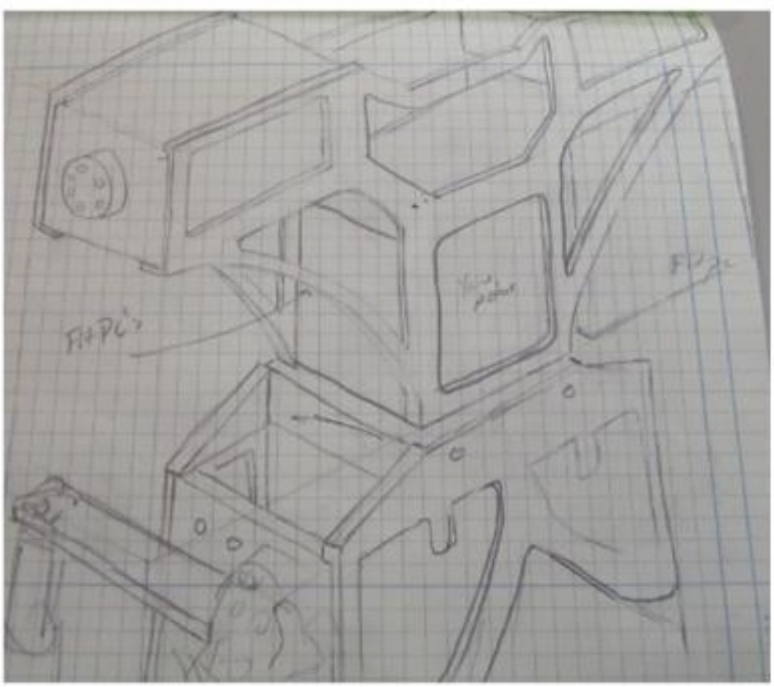
\ 

Figure 5. Yaw rotation torso design that's uses two parallels and identical side plates as main frame of the design. The motors set on these plates and bolts are used to fix the structure.

Design of the left and right CAD

It was initially desired for SAFFiR to have short shoulders, thus the team focus on the left and right concept and generated a CAD model of it. Figure 6 shows a picture of his design that includes also the first arm design from Robotis. This design is made of two side plates that are connected to the shoulder motors and to two parallels spines. The left and right motion is enable by the fact that each spine is connected to a Roll joint on each side and both spines are constrains to be parallel. The mechanism is activated by a tensioned belt which rotates thanks to a motor (black with yellow joint). As shown, the torso has also a Yaw joint and the figure 6 shows the capability for the torso to combine both motions. To throw the canister, the robot moves its shoulder to the left and rotates its torso to any requested range of angle. Nevertheless, this design was not pursued for the SAFFiR torso because it involves design and manufacturing complexities. It was concluded that this design will not be strong and stable enough to support all load. Since the benefits of this design was to increase the moment arm, it was decided to increase the width of the shoulder and to pursue the Yaw torso design.

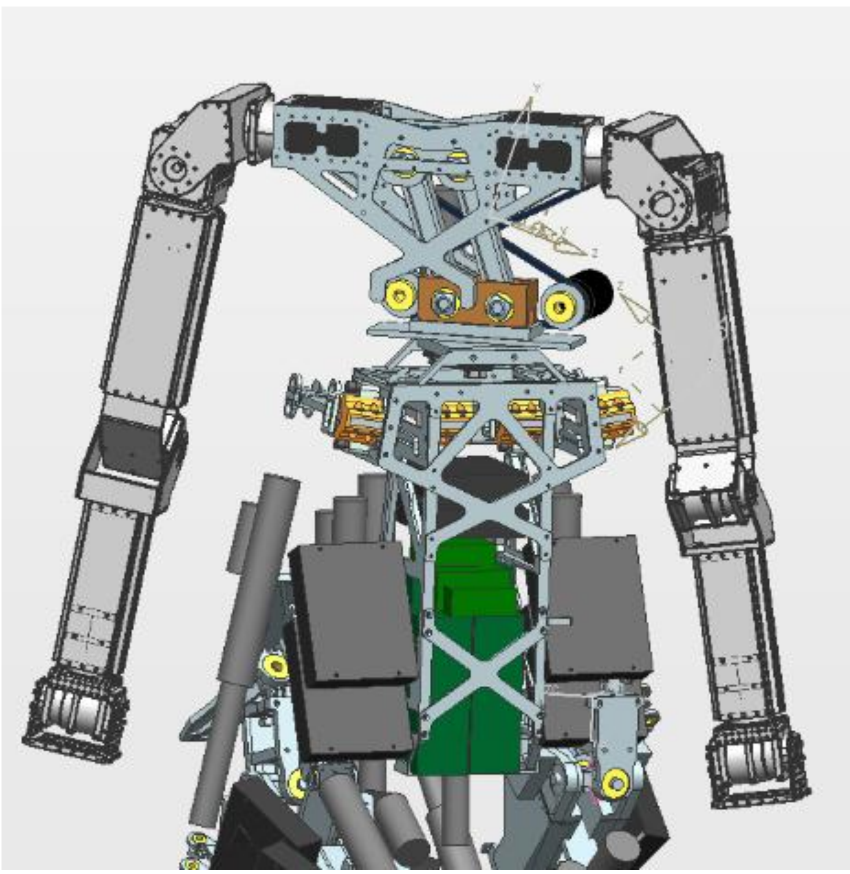


Figure 6. Left and Right torso design. The torso shifts its weight to the right and rotates to throw the grenade.

The Yaw Joint

The final design that was chosen for the torso relies heavily on an effective yaw joint. This joint needs to be robust enough to transmit all the loads between the upper and lower body yet rotate smoothly and remain rigid throughout its entire range of motion. An additional complication for this yaw joint is that it needs to be driven by a Dynamexal Pro motor which is not capable of carrying significant thrust loads.

To overcome these challenges a preloaded yaw joint design was developed where the motors shaft must only carry the torque loads seen in the yaw axis of rotation. This design combines two bearings, a precision threaded rod, and several custom components to achieve a joint that can rotate easily under high loads. Describing the details of this design is difficult without the aid of a CAD program due to the many hidden and nested components. Figure 7 shows an isometric view of the CAD model for the Yaw Joint. The black cylinder seen near the bottom of the design is a combination thrust and needle roller bearing. The second bearing will rest in machined groves between the two custom components shown transparently below.

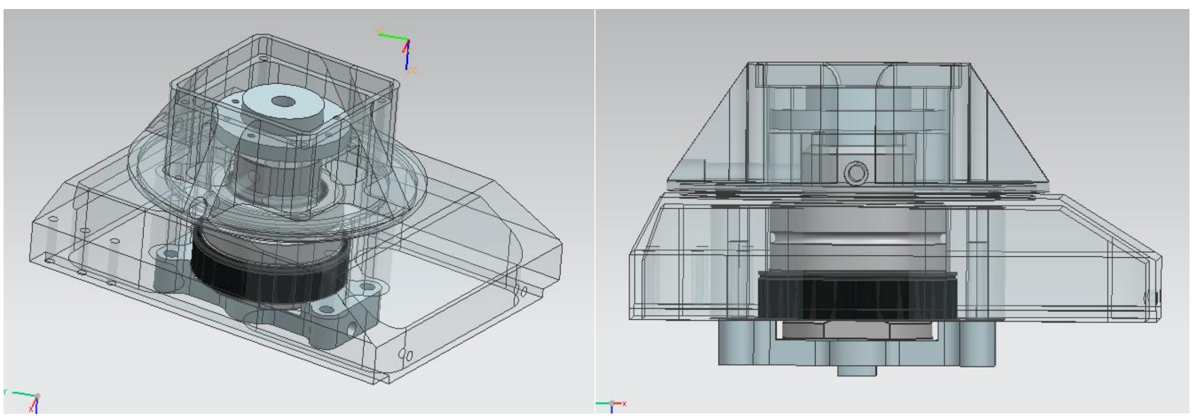


Figure 7. Isometric and side Views of Yaw Joint CAD Model. Here the translucent parts represent the two main custom components. The gray and black components represent purchase parts.

This design still needs to be finalized and manufactured to ensure that it performs as expected. In summary this yaw joint should be capable of transmitting all required loads between the upper and lower body while rotating freely and remaining rigid.

Final CAD

The final torso design is presented in figure 8. As presented previously, the structure of this design is really strong. The side plates are drawn to support all external weight and forces and internal torques. It is made to be symmetric according to the cross plan and thus simplify the design since only one side of this plate need to be designed. The motors are set on the plates and not on the screws. It is important when designing to avoid any weight support on the screws to prevent from failures. The screws are only used to fix the plates and the motors together. The design has the advantage also to be really light, one side plate weight 160g which is low. The plates are made to be really easy and fast to manufacture . It takes around 2 hours to manufacture one (according to the cam file) which is really short. Usually more than 6 hours are needed to design any big piece. Several holes are positioned on the plate to fix the motor on it and to set any kind of fixture for the sensors. Since all the holes are aligned with the thread holes of the motors these holes do not need to be thread and thus simplifies manufacturing.

Furthermore, as shown in the figure this design incorporates all the sensors. In the front and shoulders, are all sensors requirement and at the back are the fitPc's (bleue) that will be used to command the cameras and the sensors. It is also really easy to assemble. The arms can be removed by just unscrewing the bolts. There is not need to disassemble the entire torso. This is a really important point because any motor can be replaced easily and quickly in case one of a failure. Finally, the torso dimensions respect the 50 % man data and thus maintain human proportion.

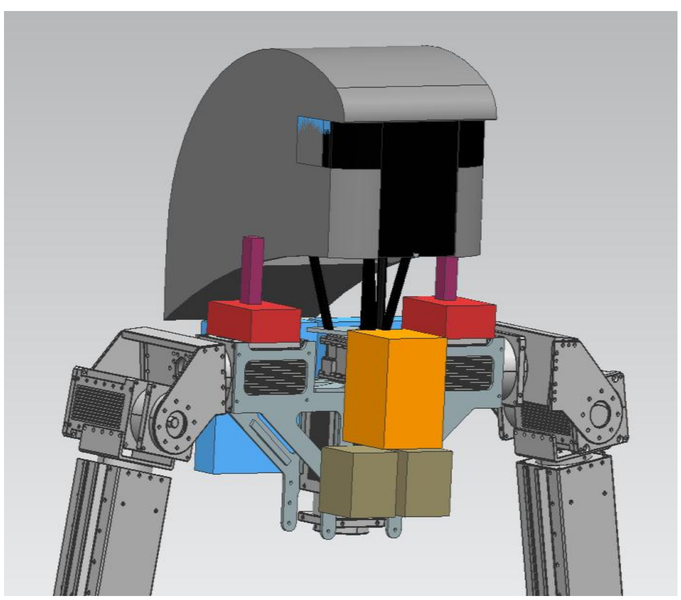


Figure 8. Final CAD model of the Torso. It includes also all the sensors located on the front and the firPC on the back.

Conclusion Set of deadline

The Torso project has been divided into two periods. The first period was from the beginning of the semester to March 27th. During this period, we first identified the customer needs which are an important point of the project since it gave us the limit and direction of the torso design. To clarify our needs, we generated the target specifications. We determined all dimensions for the torso according to the 50% man and calculated the torque and velocity required to throw the peat canister by hand calculation. Then, we generated ideas and sketches, and come up with three main concepts: Left and right torso, multi degrees of freedom spine and Yaw torso.

To determine the best concept we created a simulation of the torso to establish the benefit of a Yaw and Row joint on the throwing motion. We saw that the yaw joint was helpful for the motion of the arms and increasing the radial velocity of the canister for a torso that has short shoulders. The left and right motion also benefits that motion since it increases the moment arm. To have a better idea of the mechanism of these models, we generated prototypes that remarkably worked. The multi degrees of freedom spine worked notably well. But the complexity of this design and the difficulty in controlling the motion rendered this design ineffective. We determined that the left and right motion can be possible to design by attaching a spring on the rope. Convinced that this innovative concept may be a great solution, we generated a CAD model of it and presented to the graduate students and to Dr Hong on March 27th. The concept was well received by the RoMeLa team but the complexity behind it lead to the conclusion that the Yaw Torso would be much simpler to make and would answer all the customer needs more efficiently than the left and right torso. The main benefit of the left and right design was it increases the moment arm for a torso that has short shoulders Therefore, we decided to increase the shoulder width of the Yaw torso design to increase that moment.

Having the design selected, we entered on the second part of the project where a final CAD model had to be presented on April 24th which gave to the team a month for manufacturing. This final CAD model was presented at this deadline. It notably answers to all the customer needs. We transformed this box with random boundaries at the beginning of the semester to a satisfied product that carefully coordinates all the needs today. It is a strong and light design that will support all expected internal and external forces. It is easy to manufacture and assemble. It also respects the human proportion and can carry all the sensors and fit Pc. We are now in the process of manufacturing and we look forward to seeing the torso on the SAFFiR robot by the end of May.