Preliminary Actuator Selection

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1 Wall Following Requirement and Drive Train

1.1 Drivetrain Concept

1.1.1 Concept Generation

The autonomous system must be able to move linearly through an area as well as change direction in an area. The system will need to have precise control over both speed and position. Possible concepts include: 1: Powered, fixed wheels at the rear; turnable, steering wheels at the front. 2: Powered, fixed wheels at the front; turnable, steering wheels at the rear. 3: Powered, fixed wheels at the front and rear. Steering accomplished by varying speed on the left or right sides of the system. 4: Tank Tracks. Steering similar to the item above. 5: Drone. The system has 4 propellers arranged in a quad-copter fashion which enables the system to fly.

Variable	**Requirement**	**Reasoning**
Traction	$\mu_{traction}$: ≥ 0.8	A large $\mu_{traction}$ maximizes grip and increases predictability
Torque	Output Torque: ≥ 8 kN.m	Approximate power needed to move vehicle at 2 m/s

1.1.2 Concept Selection

Due to the size and weight requirements imposed by the Tesseract and Pyramid, a Quad-copter Drone concept is infeasible at this level. The two options which consist of two powered wheels and two steering wheels will have difficulty with uneven or rough terrain as half of the contact points with the ground receive torque from a motor. These options do not require to the system to lose traction to change direction. The tank-track option and the four-fixed wheel option will be more capable at dealing with rough and uneven terrain since all four contact points with the ground receive torque from motors. Due to the tank turning steering method, the system will be required to lose traction to turn. This could have negative implications on system longevity. The axis of rotation is always at the center point of all four wheels with this option.

1.1.3 Concept Choice

Selected Drivetrain: A pair of in-house designed Tank Tracks made from synthetic rubber reinforced by steel wire will be used with an in-house designed single-speed gearbox. As this autonomous system is required to tackle tough terrain, Tank Tracks offer the greatest traction to allow autonomous system to operate in all conditions.

1.2 Powertrain Concept

1.2.1 Concept Generation

Power will be delivered to the system via a motor or engine. The motor options include: BLDC Motor, Induction Motor, Brushed DC motor or PM Motor. All IC engine options will all be four-stroke due to environmental, lubrication and cleanliness issues with two-stroke IC engines. Engine options include: Gasoline Vs. Diesel Vs. Propane fueled, and Single vs. Multi-cylinder configurations. All options listed will require a gearbox/transmission as in intermediate system between the motor and the wheels. For IC engines, fuel is provided in liquid or gas from and is stored in traditional tanks. For electric motors, an Accumulator/Battery Box will be designed to provide electrical energy to the system.

Variable	Requirement	Reasoning
Power	Power / Motor: $\leq$ 40 kW	Approximate power needed to move the vehicle
Torque	Input Torque: $\geq$ 80 N.m	Minimize the complexity of transmission needed for output power
Efficiency	Efficiency:$\geq$ 80 %	Maximize the power transferred from the motor to the vehicle

1.2.2 Concept Selection

Internal Combustion (IC) engines introduce additional difficulties in autonomous vehicles due to hazardous refueling practices. IC engines require more sophisticated control systems to get comparable accuracy, repeatably, and smoothness when compared to electric motors. IC engines also require multi-speed gearboxes which add an additional level of complexity to the system. Electric Motors are quieter, smoother, more efficient, and more controllable which makes them more suitable for high-precision applications such as autonomous systems.

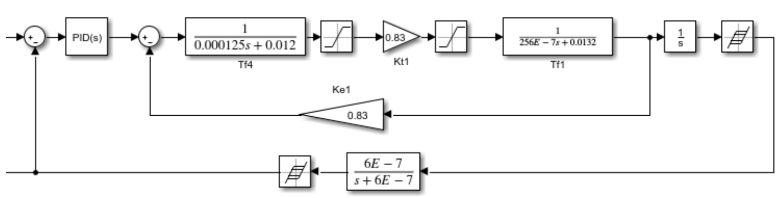
1.2.3 Concept Choice

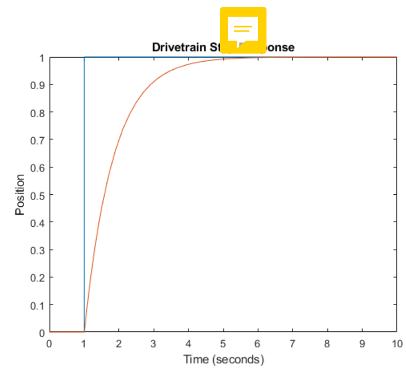
Due to the excessive loads that this system is required to endure, a very power-dense motor is required. Permanent-Magnet Brushless Motors offer industry leading power density which makes them the clear choice for this application. These components will be able to produce power figures of up to 80 kW continuously. The selected components will require an external water cooling loop to be adequately cooled.

Selected Motor: A pair of EMRAX 208 PMBL Motors.
Selected Motor Driver: A pair of Rinehart PM100DXR AC Motor Drivers.
Selected Energy Source: In-house designed Accumulator based on 18650 Lithium-ion cells.

1.3 Concept Model and Simulations

Due to the very large mass of this system, an over-damped, smooth response is desired over a very aggressive response. The model below is for one half of the drivetrain; this model will be duplicated for the left and right sides. An additional controller will be implemented to monitor the status of the left and right sides to account for parallelism and determine when to turn.





1.4 Potential Pitfalls

The selected Tank Tracks and EMRAX 208 PMBL as our Drivetrain and Powertrain of choice bring a few drawbacks and pitfalls. As specified earlier, Tank Tracks offer the greatest traction for the autonomous system, but require more power to operate (especially during turns) and are less precise in maneuverability. Some other drawbacks for continuous tracks includes lower speeds due to increased internal friction, a complex mechanical system, and its difficulty to repair when broken or dislodged.

2 Tesseract Retrieval Requirement

2.1 Concept Generation

As discussed in Report 1; the Tesseract has a mass of $\approx$ 1000 kg and is delivered on an industry-standard skid-pallet. The Tesseract Retrieval system has an option of using the skid-pallet to pick up the Tesseract. The Retrieval system must be able to reach the Tesseract which spawns on the top of a perimeter wall. Possible concepts to accomplish this include: 1: Forklift or Boom-Forklift inspired Design. Insert prongs into into the pallet and lift up to retrieve the Tesseract. Use hydraulic pistons to actuate. 2: Clamping Claw on a multi-axis robotic arm to grab the Tesseract. Use hydraulic pistons or servos to actuate the robotic arm. 3: Vacuum or Suction Cups on an arm or crane. Suck up the Tesseract into a holding bin. Use DC motors or Servos. 4: Push the Tesseract into a retrieval bin. Use DC motors or Servos. 5: Use the Tesseract's magnetic field for retrieval.

Variable	Requirement	Reasoning
Power	Power: $\leq$ 10 kW	Minimize power consumption to leave enough power for movement
Accuracy	Linearity Error: $<$ 1%	Accuracy is needed to manipulate the tesseract and pyramid

2.2 Concept Selection

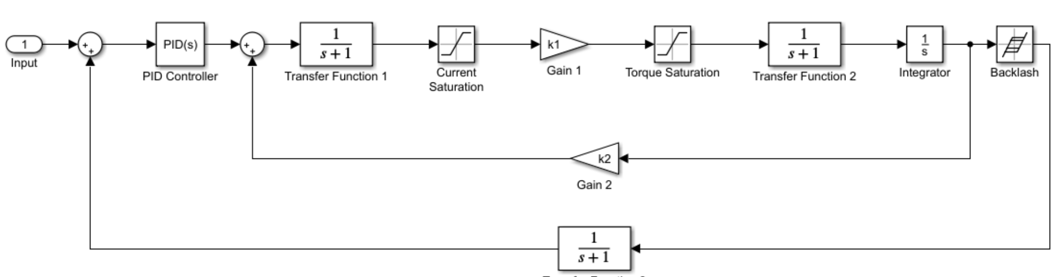
Options such as pushing the Tesseract off the wall and into a bin and using a vacuum are automatically eliminated due to the substantial mass of the Tesseract. Utilizing the Tesseract's magnetic field for retrieval is challenging due to the unpredictable direction of the magnetic field that is emitted from the Tesseract. These options are eliminated. A very large industrial multi-axis robotic arm could be implemented for Tesseract Retrieval. For retrieval, the autonomous systems would detect the Tesseract's magnetic field via the magnetometer, after which, the autonomous system would stop driving and use the robotic arm to reach out and grab the Tesseract. This method will require significant expertise in robotic arm control, and the substantial mass of the Tesseract would also pose an issue with this method. The two Forklift-inspired designs are simpler when compared to a multi-axis robotic arm. They would feature a boom with fork end defectors that will retrieve the Tesseract by making use of the skid-pallet. The boom would have two degrees of freedom, the height of the boom would be the first degree of freedom, and the angle of the forks would be the second degree of freedom. The autonomous system would use the drive wheels as the remaining degrees of freedom for boom positioning.

2.3 Concept Choice

The industrial multi-axis robotic arm option will be pursued as the Tesseract retrieval mechanism. The robotic arm will be mounted on the top of the autonomous system and will operate as described above. The end effector will feature two flat prongs which will be inserted into the Tesseract's pallet for retrieval. The arm will move the Tesseract to a transportation spot close to the center of gravity of the autonomous system. The 5 DOF arm would account for any positional errors on the treads or sensors, and would give a much larger range of robot positioning for retrieving the tesseract.

We have selected the M-2000iA 1700L 6-axis robot arm from FANUC. This arm is ideal for our application, due to its high load capacity, range, and accuracy. It meets the power requirements, only drawing 8kW on average. The maximum load capacity at the wrist is 1700kg, well above the 1000kg mass of the cube. The arm has a maximum reach of almost 5 meters, giving the robot a wide range of positioning. The arm has a listed repeatability of ± 0.27mm, meaning that it will be extremely accurate for our purposes. The arm has built in position sensors from the factory which will be used in the robotic arm feedback loop. The end effector will have a secondary magnetometer to determine the arm's position relative to the tesseract.

2.4 Concept Model



As the arm is being purchased from a manufacturer, there is little design work to be done. The block diagram shown above gives an idea of what is happening inside each motor. Again, the values are unknown as the manufacturer has not made this information publicly available. This block diagram represents one motor, and the robot arm has 6.

2.5 Potential Pitfalls

The main sources of potential pitfalls comes from the capital costs and system maintenance. Due to the complexity of the multi-axis robotic, arm we would need to investigate into cost efficient options. Furthermore, the maintenance fee and process associated with the robotic arm is very intensive. The robot will need to undergo a maintenance check after every 2-3 runs due to the outdoor environment in which it is operating. Additionally, the robot arm will be heavier than other options. While speed isn't a priority, the weight will have to be factored in when considering chassis material and layout. Compared to the to the other concepts mentioned earlier, the multi-axis robotic arm is the most code-intensive. A lot of work will need to be done to ensure all the sensors and actuators are in sync with each other. Experimentation related to the arm will be simulated in V-REP using code from Matlab.

3 Pyramid Retrieval Requirement

3.1 Concept Generation

As discussed in Report 1; the Pyramid has a mass of $\approx 2500\ kg$. The Pyramid retrieval system must be able to lift at heights over the tesseract. Various concepts to accomplish this task include: 1: Forklift or Boom-Forklift inspired Design. Use hydraulic pistons. 2: Clamping Claw on a multi-axis robotic arm. Use hydraulic pistons or servos. 3: Vacuum or Suction Cups. Lift the Pyramid via suction from an overhead crane. 4: Secure the bottom and push it over by applying force to the top

Variable	Requirement	Reasoning
Force	Maximum Load: $\geq$ 2500 kg	Must be able to lift pyramid
Stroke	Stroke Length: $\geq$ 36 inches	Lift Pyramid high enough to place tesseract underneath
Torque	Maximum Torque: $\geq$ 3750N	Torque required to lift pyramid at 1.5 m from frame of vehicle

3.2 Concept Selection

Due to the weight of the pyramid and the non-orthogonal angles of a pyramid, suction via a vacuum or suction cup is not feasible and is eliminated. A claw on a multi-axis robotic arm will also face difficulty gripping a pyramid due to its non-orthogonal angles. A forklift design has the largest weight capacity when compared to industry robotic arms. However, they offer less precision and rely heavily on the drivetrain components for positioning which does not allow for precise position control.

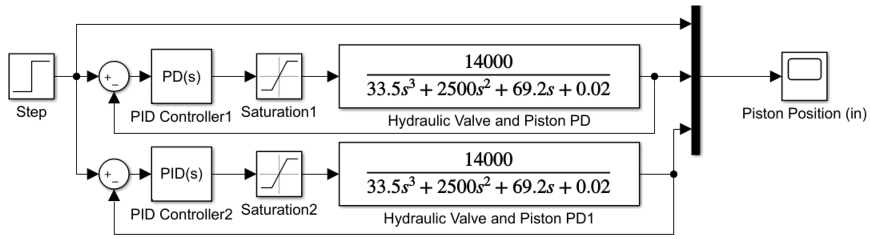
3.3 Concept Choice

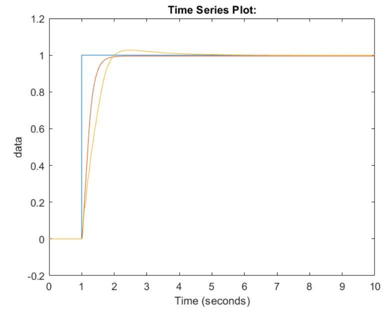
A combination of the hydraulic forklift design and the robotic arm will be used to manipulate the pyramid. The same robotic arm that is used for tesseract detection will be used to hold the pyramid in place while the forks are pushed underneath the pyramid for lifting. This option offers the greatest accuracy and repeatably over all options considered.

Selected Hydraulic Actuator: Welded–DA–Heavy Duty–Universal Mountings Model PMC-8342
Selected Pump for Hydraulic Actuator: Medium Pressure Piston Pump - PVP Series
Hydraulic Fluid: Hartland Hydraulic SAE 10

3.4 Concept Model

Since this arm mechanism is the same as the tesseract retrieval system, the block diagram will be the same. For the hydraulic lift a simulink model was created using the techniques shown in class.





3.5 Potential Pitfalls

Since the team will be using the same arm mechanism from the tesseract retrieval system, the pyramid retrieval system will share similar pitfalls.
We will need to iterate and tune the location of the IR sensor to ensure that the multi-axis arm is within reach of the pyramid. The prongs of the arm might need to be angled to ensure that it does not get stuck on the corner of the pyramid.

4 Timeline

Our team was able to follow the project timeline specified in our previous report. As a result, we have decided to keep the same timeline, with updated dates. Should our team encounter difficulty following the timeline, updates will be made in future reports to reflect the current state of work.

Week of:		
	Mar. 11	**Preliminary Actuator Selection Deliverable: Step 3 Due Mar. 15th**
		• Continue preparing and finalize report step 3 deliverable
	Mar. 18	**Evaluate Sensor and Actuators**
		• Evaluate the proposed system of sensors and actuators
		• Create a kinematic system model and perform analysis using Solidworks
	Mar. 25	**Obtain Feedback and Iterate**
		• Identify possible problems with the proposed system of sensors and actuators
		• Refine analysis for the transducers, control device, kinematics, and power supply
	Apr. 01	**Finalize Final Simulations and Report: Step 4 Due Apr. 5th**
		• Continue preparing final report for step 4 deliverable

Figure 1: Go / No Go Diagram

	Power Train			
	Induction Motor	Brushless Motor	Universal Motor	IC Engine
Accuracy	1	1		
Sensitivity	1	1		
Stability		1		1
Repeatibility		1	1	1
Implementation Ease			1	
Long Life	1	1		1
Reliability	1	1		1
Flexibility	1	1	1	

	Drive Train				
	Steering Wheels at the Front	Steering Wheels at the Back	Fixed 4 Wheels	Tank Tracks	QuadCopter
Accuracy			1	1	1
Sensitivity		1			1
Stability					1
Repeatibility					1
Implementation Ease	1	1	1	1	
Long Life	1	1	1	1	
Reliability	1	1	1	1	
Flexibility			1	1	1

	Tesseract Retrieval				
	Forklift	Robot Arm	Vacuum	Push Into Bin	Magnet
Accuracy	1	1			
Sensitivity		1			
Stability	1	1	1	1	1
Repeatibility	1	1			
Implementation Ease	1		1	1	1
Long Life	1	1		1	
Reliability		1			
Flexibility		1	1		1

	Pyramid Lifting			
	Forklift	Robot Arm	Vacuum	Push it over
Accuracy		1		
Sensitivity	1	1		
Stability		1	1	
Repeatibility		1		
Implementation Ease	1		1	1
Long Life	1	1	1	
Reliability		1		
Flexibility		1		