Autonomous Racing evGoKart - Electronic Steering and Braking

Ivan Rodionov, Genesis Jimenez, Haojun Zhang, Yikai Huang

Primary Sponsor: Jack Silberman

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University of California - San Diego

Professor: Jerry Tustaniwskyj

Abstract

This project, sponsored by lead and advisor of the TritonAI racing team Dr. Jack Silberman, focuses on combining traditional auto-racing mechanical design with innovative software controls for self-driving vehicles. The sponsor's goal is to transform a purely manually controlled electric go- kart into an autonomous vehicle capable of driving and navigating with manual or autonomous control on command. This project's motivation is the EV Grand Prix Autonomous race that will be held by Purdue University in May. This competition lays the groundwork for providing baseline autonomous skills in a cost effective manner. The specific requirement of the project is to analyze the brake and steering systems to develop functional control mechanisms, using actuators and sensors, and implement a disengagement system utilizing an Emergency Off switch. The key parameters that were considered in the selection of the actuators were speed of actuation, force/torque of actuator, resolution of stroke speed, and feedback options. After selection with the help of CAD mounts were developed and the actuators installed and tested on the kart. Through theoretical and experimental analysis it was determined that an electrical linear actuator works best for the activation of the brakes, and a steer-by-wire system for the steering of the go-kart.

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Chapter 1: Project Description

Background

Go karting is a popular activity in the United States, with almost 35 million people participating each year. This sport has sparked a lot of interest, particularly among young engineers and novice drivers. A go-kart is a small racing vehicle with little ground clearance that can only be used on flat racing tracks. This type of vehicles made with sturdy and long lasting materials are usually fast and easy to drive automobiles. They are made up of several components including a chassis, engine, steering system, braking system, and computerized controls. The steering mechanism is one of the most important aspects of a go karts design since even a small refinement in its reaction time can assist the driver. As a result steering must be trustworthy enough for the driver to have full control over the kart. Similarly, the braking mechanism is crucial to enable a go kart to come to a full stop. Both steering and braking can be conducted manually by a driver just like a standard car. Nowadays, however, one of the most pressing difficulties in the field of intelligent transportation systems is the development of unique brakes and steering via autonomous systems. That is, a ground vehicle that can be controlled remotely or by computer and can move safely with minimal human input. Autonomous racing is the pinnacle of engineering and has become a great way to push technology. Every year, Purdue University hosts the EV Gran Prix Autonomous, a race involving autonomous electric go karts from several institutions. This race, in which we will take part, is a low-cost method to give ground for university students to acquire baseline abilities. This project looks at converting a mechanically controlled, electrically driven go kart into an autonomous vehicle capable of driving and navigating with only partial human aid as desired by the TritonAI sponsor.

Review of Existing Solutions

In search of the braking solutions, Triton AI team have already made another similar gokart with autonomous braking. Their solution includes using a heavy duty linear actuator to push the braking lever to fulfill braking power. They use Kar-tech model 1A0014E as actuator and use two 1mm laser cut acrylic boards as mounting. In general, we think a linear actuator with a custom made mounting should be sufficient design for our kart, but we should do more research on force needed for the actuator and probably design a mounting with higher durability since it will be used hundreds of times in a racing circumstance.

On the other hand for the steering part, Triton AI also tried their solution for steering using a large servo motor physically connected to the steering rod to achieve it. While we think if we want to achieve both manual and automatic steering by a switch a physical connection of servo motors to the steering rod would not be the best solution. Since servo motors can easily step gears when they are turned by hands. In the industry of autonomous vehicles there is a popular solution used by many modern cars such as tesla and toyota, etc. It is called steer by wire, which means the steering wheel is not physically connected to the steering rod but instead only connected by a wire(electric wire for digital signals). The steering wheel provides a signal to the steering rods which is controlled by powerful motors to turn the wheels. We believe it should be the most reasonable choice for our project but we need to simplify the design for a real car to a small go kart.

Statement of Requirements

The evGoKart will be racing as an autonomous robot with two subsystems, steering and braking, controlled by computer input. At the same time, there will be a mechanism that allows a human driver to override the computer and control the steering and brake manually.

The evGoKart must have a manual-control or an emergency off button to enable manual control for a human driver. It will be nice to disengage the computer control by detecting the pressing motion of the brake pedal or sensing the steering wheel motion.

Deliverables

1. One braking system mounted on the go kart
    - Braking actuator of our choice
    - Mounting customly made for actuator
    - Necessary controllers needed for controlling the actuator
2. One steering system mounted on the go kart
    - Steering wheel actuator for moving the steering wheel
    - Sensors for sensing the steering wheel position
    - Controllers and connects to pass down signals to steering motors.
    - Steering motors and mountings to steer the wheels.
3. One Emergency Off (EMO) system
    - Button for easy deactivation of autonomous control.
    - Braking and Steering systems allowing for both full manual and autonomous control, with

Chapter 2: Description of Final Design Solution

The final design solution consists of the linear actuator to assist with braking and a redesigned mount that sits further out of the seat. This design will provide more space for the human driver's thigh. And the steering system consists of the servo motor and gearbox to provide required torque to steer in the race track. Both subsystems are able to be controlled by computer input, and the built-in clutch of linear actuator and external clutch for steering servo allow the human driver to override the autonomous control. Each of these solutions were meticulously constructed to ensure that it not only performs its function but also integrates into the go-kart as a whole.

Steering system:
The vehicle's steering system control on this go-kart must be able to move the wheel in a manner equivalent to that of a fully capable person with a steering wheel. The steering is intended to exceed the tremendous friction forces generated by the weight of the kart plus ground and tire contact as the wheels are turned. The system has a number of components that enable it to complete its goal. The steering control is made up of the following components:
The servo motor and gearbox will be fastened to a plate affixed to the front support. (tentative)

Braking system:
In the braking system the main objective was to relocate the current actuator mount for autonomous only control and provide enough space for a human driver to sit in the goKart.

The mount for the linear actuator was relocated out of the way of the seat. The linear actuator that was chosen for this design is the Kar-Tech Linear Actuator. It runs on a 12V supply of power and uses CAN bus for communication. CAN bus allows the actuator to maintain a steady stream of signal and provide a reliably feedback control loop, this makes it perfect for the brake application. The design utilizes the actuator primarily for its superior performance in providing a linear force of 90lbf which exceeds our design requirements of 70lbf as established by the

Chapter 3: Design of Key Components

The key components of the steering and braking solution for the autonomous goKart are the linear actuator for the braking system and the steering servo for the steering

Linear actuator

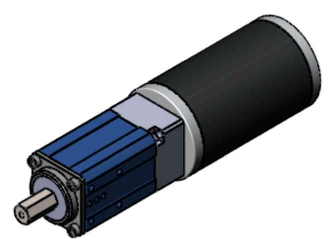
The linear actuator needs to handle over 70 lbf dynamic and static force in order to stop the go kart and the built-in clutch mechanism allows the master cylinder’s lever to retract backward with the stroke blocking when the power is off. The built-in sensor and feedback option, CAN bus, provide the function of autonomous programming.

	Kar-tech 1A0014E 	Firgelli FA-PO-35-12-2 	ThomsonElectrak 1SP 
Cost ($)	419.99	152.95	350
Dynamic force (lbf)	90	35	25
Static force(lbf)	200	70	300
No load Speed (inch/second)	3.00	2.00	3.00
Note	Built-in clutch, contactless sensor, expensive, does not interfere the stroke movement when no power	ACME screw type, built-in potentiometer, affordable, need extra design for disengagement	ACME screw type, built-in potentiometer, expensive, provide adequate torque speed, need extra design for disengagement

The design of this brake system's mount needs to consider the stabilization from the motion vibration, dynamic of the brake process, and the comfort for the human driver. By putting the brake system on the side of the driver seat, the driver can have more space to perform the manual braking but not interfere with the physical connection between the master cylinder and the pedal. Instead of a steel rod with fixed length, The galvanized steel cable performs a flexible but rigid connection to the pedal and master cylinder. It is crucial to have the ease of fabrication for the brake mount, which led the 6061 aluminum sheet to be the primary material for machining.

Steering servo

The steering servo system needs to provide 35 ft lbf torque and 100 RPM of a stand still kart. Since most of the servo motors in the market cannot perform such torque, the steering servo system needs an external gearbox to meet the project requirement. Also for safety reasons, it is necessary to have a clutch mechanism to switch the computer input to human driver control.

	CIM motor + CIM gearbox (20:1) 	Allied Motion motor and gearbox package 
Price ($)	143	Wait for quote
Voltage (V)	12	24
Geared torque (Nm)	48.40	50.17
Geared speed (RPM)	265.5	110
Note	Does not have control input, need external feedback sensor	CAN bus communication, need external feedback sensor

	KEB electromagnetic clutch	OGURA electromagnetic clutch

		
Price ($)	Wait for quote	Wait for quote
Voltage (V)	24	12/24
Torque (Nm)	0.5-1000	Max 50
Note	Not for end user	Compact size

The mount for the steering system needs to take into consideration the size of the whole system, the bending torque on the motor shaft, and the overall configuration for radar setup.

Chapter 4: Prototype Performance

Theoretical Predictions

Steering:

Throughout the design process for the steering solution, the primary objective was finding the required torque that would be required to turn the wheels on the kart. Another consideration was to look into existing research and establish a baseline benchmark for the ideal steering response, consisting of speed and resolution, that would be required in implementing a steering solution.

The estimating approach of steering torque was developed using a mathematical model on the essential idea that the torque required to spin the wheel should be larger than the frictional resistance torque. In order to estimate the steering torque, some assumptions were made:

1. Go-kart is in static conditions. Static steering torque at halt is a critical component in vehicle steering portability.
2. Front to rear weight ratio is 40: 60
3. Coefficient of friction is taken as 0.7

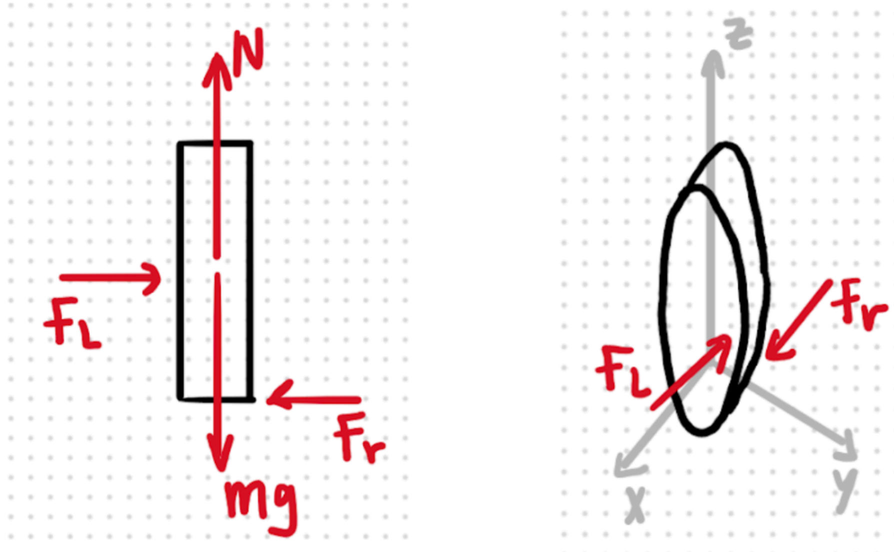


Figure 1: Free Body Diagram of one of the go-kart front wheels (This image will be replaced later)

$$F_L = Lateral\ force$$
$$F_R = Friction\ force$$
$$T_{kp} = Total\ kingpin\ force$$
$$B =$$
$$E =$$
$$T_L = Lateral\ push\ from\ rod$$
$$F_{TR} = Force\ on\ tie\ rod$$
$$r_A = pitman\ arm\ radius$$

Some important equations we used for the theoretical estimation of the steering torque are as follows:

$$\Sigma F_x = 0$$
$$-F_R + F_L = 0$$
$$F_L = F_R$$

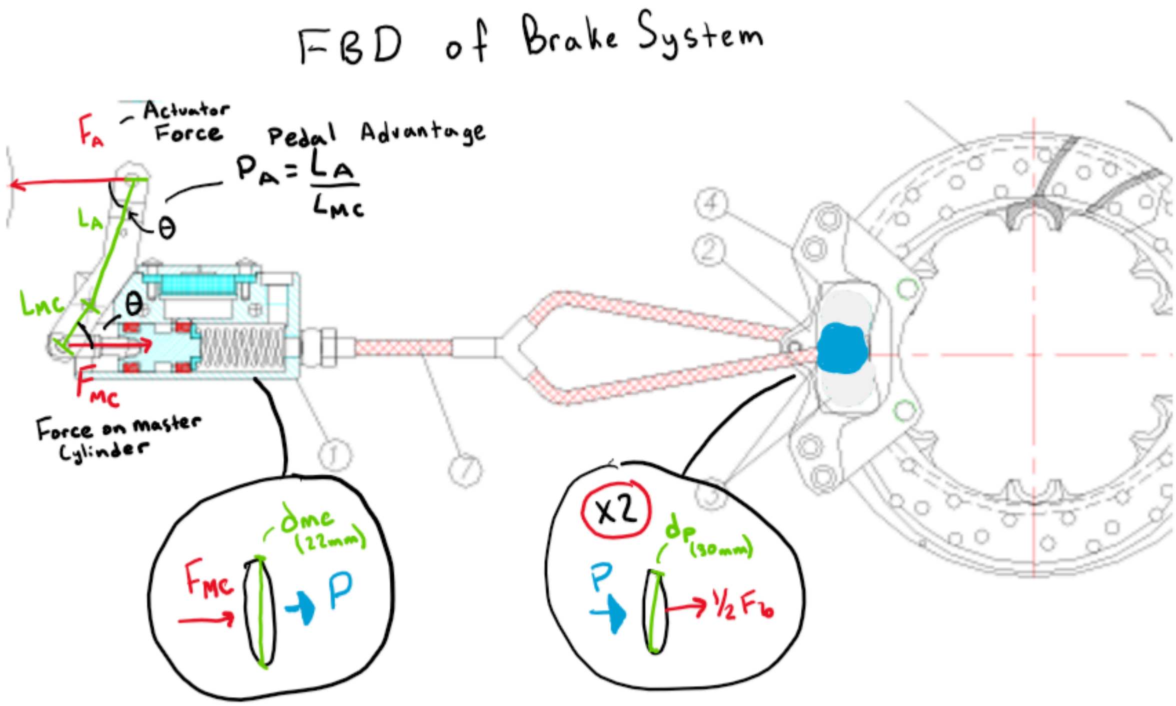
$$\Sigma F_y = 0$$
$$N - mg = 0$$
$$N = mg$$

$$T_{kp} = F_L * \sqrt{((B^2/8) + E^2)}$$
$$T_L = F_{TR} * r_A$$

Using these equations we were able to conclude the steering break-away torque of about 38 Nm (28 ft lb). This static steering torque estimation was then compared with experimental results. The comparison reveals that the estimation findings provided are accurate.

Braking:

For the design of the braking system, the primary objective was estimating the dynamic and static force that pushes the lever of the master cylinder and stops the go kart. The reaction time of human braking determined the speed of the actuation under specific load. The brake system needs an electrical or mechanical mechanism to perform human driver manual control when the autonomous program is down. The prediction for the force required to stop the kart was deduced from a force analysis performed on the system, starting from the master cylinder down to the tires contacting the road. There were a few assumptions that were made, the weight of the kart and the coefficient of friction were the main constants that were predicted with the help from online sources. Another large assumption that made the analysis somewhat inaccurate was the consideration that the master cylinder acted as a force multiplier and not as a standalone device with springs and back pressure. The lack of consideration for the springs and back pressure led to the analysis being skewed from the real testing performance. This analysis includes the assumptions that we taken numerically.



Dimensions:

Diameter of Master Cylinder Piston:

$$d_{Mc} = 22.2mm$$

Diameter of Caliper Piston:

$$d_p = 30mm$$

Length of Actuator Lever:

$$L_A = 5.9cm$$

Length of Master Cylinder Lever:

$$L_{Mc} = 2.4cm$$

Mechanical Advantage of Lever:

$$P_A = \frac{L_A}{L_{Mc}} = \frac{5.9cm}{2.4cm} = 2.4583$$

Moment Balance at Master Cylinder:

$$\sum M = F_A \sin(\theta) L_A - F_{Mc} \sin(\theta)\, L_{Mc}$$

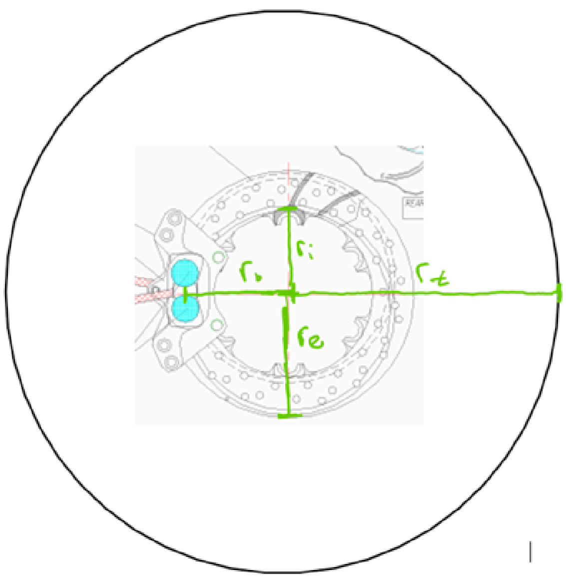
$$F_{MC} = \frac{F_A L_A}{L_{MC}} = F_A P_A$$

$$F_{MC} = F_A P_A$$

$$P = \frac{F_{MC}}{A_{MC}}$$

$$A_{MC} = \frac{\pi d_{MC}^2}{4} = \frac{\pi (0.0222)^2}{4} = 0.000387\ m^2$$

$$P = \frac{0.5 F_P}{A_P}$$



$$F_b = 2 P A_P$$

$$A_P = \frac{\pi (d_P)^2}{4} = \frac{\pi (0.030)^3}{4} = 0.0007069\ m^2$$

$$F_b = \frac{2 F_{MC} A_P}{A_{MC}} = \frac{2 F_A P_A A_P}{A_{MC}} = 8.981 F_A$$

Measuring the dimensions of the wheels:

$$r_i = 69mm$$

$$r_e = 100mm$$

$$r_b = 84.5mm$$

$$r_t = 12.7cm = 127mm$$

Assume:

$$m_c = 208kg\ (460lb)$$

$$\mu_{dry_{rubber}} = 0.7$$

Assumption: The torque on the brakes cannot exceed the torque on the wheels due to friction. As if the brakes provide more torque than the friction with the ground the karts wheels will lock up and slide

$$\tau_{brake} = \tau_{friction}$$

$$F_b r_b = F_f r_f$$

$$F_f = \mu N = \frac{\mu}{2} m_c g$$

$$F_b = \frac{\mu m_c g r_t}{4 r_p} = 1072.22N$$

$$F_A = \frac{F_b}{8.981} = \frac{1072.22}{8.981} = 120N$$

Through this analysis the estimation until the wheels lock up in the kart is at 120N.

Test Conditions

The test conditions chosen for the testing and analysis of the steering and braking involved replicating the inputs a human can provide and establishing baseline parameters that were then matched with actuation devices.

Steering System:
For the steering test, an adaptor was manufactured and applied to the sheeting shaft. The adapter allowed for a torque wrench to be fitted onto the steering shaft and the steering torque required to turn the wheels in their maximal positions to be measured.

Results

Braking System:

In the practical test of the brake the maximum force that was experienced was 70lbf, the figure above demonstrates how the test was conducted, with the load cell being strung up between the pedal on the left and the arm of the master cylinder on the right.

Chapter 5: Design Recommendations and Conclusions

Design Recommendations of the future

If the major components of the project are coming with a big size, it is important to have an accurate CAD of the overall go kart to estimate the position and the orientation of those components.

Safety Considerations

As in any engineering project, safety problems must be considered. The driver is the first and most important issue in this project. To provide safety we will incorporate a fail safe steering and brake system to prevent the driver from injury while driving the autonomous ev go-kart if there is a malfunction in the control circuit. For braking, the implementation of a two-stage braking system is our solution to this challenge. The linear actuator we will be utilizing would be disconnected which would be activated by an EMO or emergency off button. The second would be a brake pedal, which would be physically connected to brake pads and, when pressed, would produce friction to the tire surface, causing the tires to stop.

Applicable Standards

CAN-Bus motor control standard - A programmable communication standard between motorized devices, in this case a Linear actuator, and its controller. The Kar-Teach actuator comes with a J1939 standard that is used primarily in Automotive configurations. This control standard for all kinds of sensors and motorized mechanical systems allows for seamless configuration of multiple systems and allows all systems to use one single line of signals with different identifier codes for each system. This standard is useful for this application as it provides easier precise control, although it requires a Unix based system to process the signals.

Standardized materials

- **20mm T-Slotted Framing -** Readily available and standardized to fit 5mm bolts with inserts. Made of Aluminum it is strong but light and able to withstand high load applications.
- **1/8 inch thick aluminum -** inexpensive and readily available, this allows for fast prototyping. Standardizing aluminum thickness of the stock that can be acquired allows

for designers and producers to align their designs to mass producible and easy to acquire material available to anyone.
Weather Resistance Standards - as on any vehicle the equipment on the evGoKart has to withstand some exposure to the elements that might damage equipment. Thus standardized weather resistance ratings were considered as some of the criteria when selecting the actuator for the brake and system for the steering. The IP67 rating is a dust and water resistance rating that is meant that the equipment is protected from extended exposure to dust and short durations of submersion underwater which is much

Impact on Society

While global warming and extreme climate changes are becoming the prime topic of the world, it is essential to find a solution reducing the impact of carbon emission. The concern of automobiles has been considered as one of the greatest contributors of air pollution and greenhouse gas emission. As the development of fossil fuel and combustion engines reach to the limitation, autonomous electric cars will be the major trend of the future mobile industry. The development of artificial intelligence provides precise energy management and short reaction time, which facilitates people to travel with safe, low-cost, and environmentally friendly methods. However, there is a moral discussion of the collaboration between the AI input and human control when encountering danger on the road. This project is an approach of the interaction between the computer input and human driver. The AI enables the go kart to minimize time usage in every lap by performing accurate position control on the track. The durability of the batteries is extended by proper management of electricity distribution. The design of the disengagement mechanism allows the human driver to override the AI's steering and braking control while the human driver detects the incoming danger, or the machine does not make enough force input.

Professional responsibility

As engineers it is important to consider the implications on the values in society when developing AI. Artificial intelligence has been a topic of debate from its sci-fi movie implications and is a topic in society's values on the trust that is given to computers and technology. It is one of our responsibilities to develop AI technology with a fail safe switch that can reliably turn off autonomous control and provide the human

In development of the design for the brake actuator it is important to also consider the strength of components that are being used in the build and test them for strength in their appropriate applications. As the safety of the passenger in the evGoKart depends on the components not failing during testing and racing.

As the evGoKart project is a collective project by the Triton AI team the results collected have to be presented to future members of the team that might be working on the kart. Thus it is important that proper documentation is made so the research that has been completed can be used to further develop the design. The use of the acquired research can be used for developing new designs and further analyzing better solutions to run the kart.

Lessons Learned

It is important to take into consideration that the design we made from CAD is not whatever we want it to be. When designing things we have to consider the ease to manufacture and the cost of manufacturing. It will be really expensive if we try to machine all of our designs. In some cases we learned to use off the shelf parts and modify them to make them useful for us.

Acknowledgments

References

Appendix:

Appendix A-1: Linear Actuator for Brake Application

Functional Requirements:

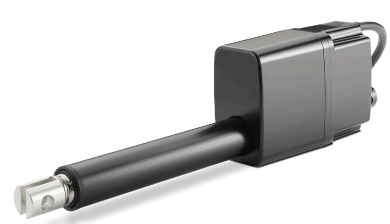
- Apply a great enough linear force on the master cylinder lever to provide enough pressure to the caliper to stop the kart.
- Must provide enough power so the force is applied fast enough to provide a short enough stopping distance.
- Provide feedback through a serial connection so the device can be programmed, preferably through the existing CAN bus system.

Possible design options:

1. ***Kar Teck Linear Actuator (Existing) - Part Number 1A0014E***

- Provides 90lb of force
- 3 inch bore with precise control of motion
- Speed is not listed but was tested at the lab to be approximately 3 inch/sec
- Internal clutch allows the actuator to return back to center position when power is cut
- 8.875 inch x 4 inch x 1.875 inch footprint
- 25% duty cycle
- Feedback is provided through CAN bus control

2. ***Thomson Linear Actuator - Part Number: MD12A050-0100LXX2NNSD***
   - Provides 250N of force
   - Speed of 2.05 inch/sec
   - Robust construction and IP66, IP67, IP69K weather resistance
   - 25% duty cycle
   - 2.13 inch x 3.63 inch x 5.2 inch dimensions of the gearing and electronics box.



- Feedback is provided through CAN bus control

3. ***Firgelli Automations Feedback Rod Linear Actuator - Part Number: FA-PO-35-12-2***

- Provides 35lb of force dynamically, and 70lb of force statically (under brake application once slack is removed from the master cylinder the static force is significant)
- Speed: 2 inch/sec
- IP54 weather protection
- 20% Duty cycle at max load
- 3 inch x 5.5 inch x 1.57 inch dimensions of motor and electronics portion
- Feedback is provided with a 10k ohm potentiometer

Actuator comparison chart:	**Pros**	**Cons**
Option 1: Kar Tech	- Available for testing at the moment - Precision of 0.01 inch - Control through CAN bus system - Internal clutch that allows the actuator to release when power is cut	- Price of replacement is $400, higher than other options - Large dimension of the housing making it harder to position in the kart ergonomically -
Option 2: Thomson	- Cheaper alternative to Option 1 at $257 - CAN bus control allows easier implementation - Speed is 2 inch/sec so this will allow it to apply the brakes (<1sec)	- Lead time of 50 days - Force actuator provides is only 250N which is cutting it very close to the theoretical value. - Not a lot of mounting surfaces and not square shape making mounting tricky
Option 3: Firgelli	- Cheapest option at $150 - Provides more than enough speed to quickly(<1sec) apply the brakes, 2 inch/sec - Ships the fastest - Potentiometer allows for position feedback to be constant over power cycles	- More integration required with potentiometer as signal must be converted. - 35lb of force isn't enough to stop the kart and the 70 lbf value isn't leaving a lot of room for

Resources:

Some of many keywords used:

1. CAN bus linear actuator
2. Hall Sensor
3. Linear Actuator with hall sensor
4. linear actuators with position control
5. linear actuators with potentiometer position feedback

Databases/Websites found:

1. Timotion.com - website explaining the difference in feedback sensors available in linear actuators https://www.timotion.com/en/news-and-articles/part-6%3a-electric-linear-actuators-with-feedback-sensors
2. Utilizing Hall Sensors - video explaining how hall sensors work https://www.youtube.com/watch?v=nBexm2UM84k&ab_channel=FIRGELLIAutomations
3. Thomson Sales Website - website outlining all the different linear actuators that Thomson offers https://www.thomsonlinear.com/en/products/linear-actuators#products
4. Peaco Support - distributor of automation components https://peacosupport.com/heavy-duty-linear-actuator-2000-7000n
5. Kar-Tech - website detailing linear actuator option 1 https://kar-tech.com/12-24v-linear-throttle-actuator-1.html
6. Firgelli Automations - website selling electric linear actuators https://www.firgelliauto.com/

Contacts Made:

1. 540-633-3549 - Thomson Sales Department
2. 866-226-0465 - Firgelli Sales

Appendix A-2: Rotary position sensor for brake pedal

The objective of this project is to design actuators and sensors for an autonomous electric kart that allows computer input to control steering and braking and enables a human driver to override the mechanism by emergency off button. The component of this analysis is the sensor for the brake pedal. In order to control the disengage and re-engage brake mechanism, it is important to collect angle data and feedback of the brake pedal.

From the previous brake analysis, the functional requirements are as follow:

● The minimum adjustment angle range of the sensor is greater than 50 degrees. ● The minimum voltage output is smaller or equal to 5 volt DC in order to connect with Arduino. The secondary considerations are:

● Low friction is ideal to maintain the effective force from foot to the brake as much as possible. ● Good robustness enables the sensor to handle the vibration and turbulence while the kart is driving.

● It would be better if the sensor has dust and water resistance to protect the functionality in different weather conditions.

Based on the requirements above, the searching process was limited to three key words: “rotary,” “position,” “sensor.” After reading through multiple datasheets and introductions of automotive sensors applications, the searching result generated three major rotary position sensors for the project: potentiometer, inductive sensor, and hall-effect sensor. All of them can handle the measurement and feedback of the pedal, and they differ from each other by the feasibility to the requirement and considerations. Because each sensor has numerous manufacturers and models, this report will choose the models depending on the stock status and the popularity for purchase ease in the future. There were:

- 3382H-1-103, Bourns Inc.
  - This sensor is a typical resistive sensor for rotary position measurement, which is the same as the potentiometer. By turning the hole, the inside wiper will change its position to vary the resistance of the sensor, thus, the analog signal will be produced by the voltage and resistance change.

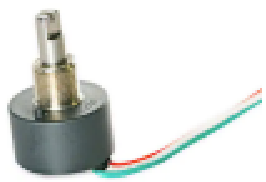
Electrical Characteristics

Standard Resistance Range .... 2.5K to 100K ohms
Resistance Tolerance .... ±30 % std.
Linearity .... ±2 %
Resolution..................... Essentially infinite
Insulation Resistance @ 500 VDC .... 100 megohms min.
Dielectric Strength
  Sea Level .... 500 VAC
  70,000 Feet .... 350 VAC
Adjustment Angle..................... 330 ° nom.

- 02183000-000, TE Connectivity Measurement Specialities
  - This sensor is an inductive sensor with adjustment range 0-120 degree. The built-in coil generates an exciting electromagnetic field by AC voltage. When the conductive material passes through the exciting magnetic field, the material will produce inverse current and magnetic field. The built-in electric will evaluate the voltage signal of two magnetic fields to get the position data.

ELECTRICAL SPECIFICATIONS	
Input voltage	5±0.25 VDC
Input current	21mA maximum
Angular range	0 to 120 degree
Non-linearity	±0.5% of FSO
Output at range ends	+0.5 to +4.5 VDC (ratiometric to input voltage)
Sensitivity	6.67mV/V/degree (ratiometric to input voltage)
Temp coefficient of output	±0.02% of FSO per °F [0.03% of FSO per °C], over operating temperature range
Output current	5mA maximum
Output impedance	1Ω maximum
Non-repeatability and hysteresis	0.1% of FRO maximum
Frequency response	200 HZ @ -3 dB

- 285CCDFSAAA4C1, CTS Electrocomponents
    - This is a Hall-effect sensor with adjustment range 360 degree. When the magnet rotates above the powered Hall element in a close distance, the voltage difference is generated by the current flow change, thus, the electronics can compute the position data by evaluating the voltage difference.



Electrical Specifications

Sensor Function		Min	Typical	Max	Unit
Output	Analog				
Independent Linearity		-0.5%		+0.5%	
Hysteresis				0.2%	V_{sup}
Output Voltage		5%		95%	V_{sup}
Output Overvoltage Limits		-6		+18	VDC
Output Current		-8	1	+8	mA
Output Load		5	10		kΩ
Input Voltage		-10%	5	+10%	VDC
Supply Voltage Absolute Limits		-18		+18	VDC
Supply Current			10	15	mA
Resolution	12 BIT at 360°				
Dielectric Strength	1 minute			750	VDC
Insulation Resistance	at 500 VDC	1000			MegΩ
Electrostatic Discharge (ESD)	HBM	-4		+4	kV

Price:

- 3382H-1-103, Bourns Inc. : $ 2.59
- 02183000-000, TE Connectivity Measurement Specialities: $238.3
- 285CCDFSAAA4C1, CTS Electrocomponents: $38.61

Summary

Sensor	Pros	Cons
3382H-1-103, Bourns Inc. (Potentiometer)	Cheapest, Lowest weight, Smallest dimensions, Precise absolute position, Dust protected	Prone to wear, No protection against ingress water, Largest linearity, Shortest cycle life
02183000-000, TE Connectivity Measurement Specialities (Inductive)	Protection for ingress Dust, Contactless mechanism, No wear, Precise linearity, Lowest toque, Long cycle life, Widest operating temperature range	Most expensive, Lowest angular range, No protection against ingress water, Heaviest
285CCDFSAAA4C1, CTS Electrocomponents (Hall-effect)	Protection for ingress Dust and water, Contactless mechanism, No wear, Precise linearity, Relatively cheap, Long cycle life	Vulnerable to magnetised environment, High temperature affects characteristics drift

Conclusion

For this project, the 285CCDFSAAA4C1, CTS Electrocomponents is the best option. The protection of dust and water can ensure the functionality without the concern of most weather conditions. Contactless mechanism can protect the sensor from aggressive torque. The wide angular range gives the possible feasibility to other components of the go kart.

This Hall-effect sensor has similar advantages with the inductive sensor but has cheaper price, which is essential for the budget consideration.

Reference:
Keyword - rotary, position, sensor
Information for 3382H-1-103, Bourns Inc. obtained from
https://www.bourns.com/pdfs/3382.pdf Information for 02183000-000, TE Connectivity Measurement Specialities obtained from
https://www.te.com/commerce/DocumentDelivery/DDEController?Action=srchrtrv&DocNm=R120LC& DocType=Data+Sheet&DocLang=English
Information for 285CCDFSAAA4C1, CTS Electrocomponents obtained from
https://www.ctscorp.com/wp-content/uploads/285.pdf

Appendix A-3: Steering Angle Sensor

This component analysis is on the steering wheel angle sensor of a hybrid (computer and manual control) evGoKart. For this analysis, we consider various characteristics to determine the optimal rotary sensor for acquiring feedback on the evGoKart steering wheel position.

We were given an autonomous racing vehicle chassis with an ackerman steering wheel design and a 280 degree steering rotation that, ultimately, would need to be capable of both electronic and manual control. One of our tasks is to find a high accuracy, cost effective, reliable, and robust position sensor for the steering wheel system. Its functional requirement must be to effectively transmit steering angle data to the electronic steering for precision and safety. In this case, a rotary potentiometer will be used because of its simple configuration, reliable property, ease of implementation and big- power output. Plus, a potentiometer is sufficient for a moveable object that has a 280 degree limit rotation. Thus, we wish to find an adequate potentiometer to be mounted on the steering wheel column.

First, we carefully considered the specifications of the most effective potentiometer for our evGoKart. This descriptions is the following:
(1) high precision to create the optimal torque and apply the stator field at the correct angle, guarantee precise position feedback for the motor control.
(2) low cost
(3) reliable
(4) simple integration, the potentiometer slider must directly attach to a 28 mm column that is part of the steering system.

Contemplating these characteristics, we began our research. First, we used an internet portal for supplier research, knowing that there are various product sourcing firms. An initial search for rotary potentiometer sensors gave us 25 results of companies that produced these position sensors. Even though these are not many companies, there was a wide range of potentiometers to choose from. Hence, we addressed the resistive track of different potentiometers to diminish our options. Unlike carbon film and wire-wound pots, we discovered that conductive plastic resistance or cermet type potentiometers are used for high precision and low noise applications, and have a smooth low friction electrically linear resistive track, resulting in low noise, long life, and excellent resolution.Therefore, our search was modified to find specifically conductive plastic resistance type or cermet type rotary potentiometers.

We identified three sensors that fulfilled the specifications previously indicated after browsing through catalogs of every available business.

1. Bourns inc. series 3862 (3862C-202-502AL)
2. Bourns inc. series Pro Audio 51 (51AAD-B28-A15L)
3. Vishay Sfernice series P11S (P11S1V0FLSY00104KA)

Then, we collected data on these rotary potentiometer steering angle sensors through deep search in web catalogues.

1. **Bourns inc. series 3862 (3862C-202-502AL) :**

Type: Cermet Resistive Temperature Coefficient: +/- 150ppm/℃ at -40℃ ~ +125℃
Size: Round -0.5” Dia x 0.453” H (12.70mm x 11.51mm) Resolution: essentially infinite
Rotation: 295° Weight: 25 grams
Rotational life: 50,000 cycles Load life: 1,000 hours

2. **Bourns inc. series Pro Audio 51 (51AAD-B28-A15L):**

Type: Cermet Resistive Temperature Coefficient: +/- 150ppm/℃ at +1℃ ~ +125℃
Size: Rectangular -0.521” x 0.492” Face x 0.521” H (13.25mm x 12.50mm x 13.25mm)
Resolution: essentially infinite
Rotation: 290° Weight: 8.5 grams
Rotational life: 25000 cycles Load life: 1,000 hours

3. **Vishay Sfernice series P11S (P11S1V0FLSY00104KA):**

Type: Cermet Resistive Temperature Coefficient: +/- 150ppm/℃ at -55℃ ~ +125℃
Size: Rectangular -0.521” x 0.492” Face x 0.521” H (13.00mm x 12.50mm x 13.00mm) Resolution: essentially infinite
Rotation: 300° Weight: 9 grams
Rotational life: 50000 cycles Load life: 1,000 hours

	cost	tolerance	Pros	Cons
Bourns inc. series 3862	$18.95	+/- 10%	good accuracy, high lifespan, wide resistance range, good resolution.	limited in degrees of rotation, largest in weight, high cost

Bourns inc. series Pro Audio 51	$8.43	+/- 10%	lowest in cost, lowest weight, gangable, wide resistance range, good resolution.	medium in accuracy compared to others, lowest rotational life, lowest degrees of rotation
Vishay Sfernice series P11S	$15.14	+/- 10%	highest degrees of rotation, high lifespan, wide resistance range, good resolution.	high cost, high dimensions, medium weight.

Citations: https://www.bourns.com/, https://www.vishay.com/, https://www.hoffmann-krippner.com/pdfs/choosing-the-right-potentiometer.pdf

Keywords: Potentiometers, Variable Resistors, Rotary Potentiometers

Appendix A-4: Steering Actuator

Introduction

In our team project we are building an autonomous driving electric go kart. Our goal is to design and implement a system of braking and steering that not only takes a computer input but also can respond to human override. In this analysis I want to discuss what kind of motor and design we could possibly use in the steering system.

Function needed

The steering system needs to allow a computer digital signal input to control the steering and also allows a human interference to steer it when an emergency happens.

3 possible choices

After doing a little bit of research on the internet about how people do in the industry and research there are three possible solutions that we can use. In the industry of autonomous vehicles they use a technique that is called steer by wire. By using steer by wire there is no physical contact between the steering wheel and steering rack. Instead the rack is turned by a steering actuator and the wheel is connected to a handwheel feedback motor. Also, there is another way that we will physically connect the steering wheel to the rack and add an actuator to turn the steering rod. Here is a chart of the 3 choices.

Name	Pros Cons Price

i00600 Torxis Servo 1600 oz.in. 1.5 sec/90 deg	Not very expensive, Can't drive by 289.00 Comes with an hand, absolute encoder, Will cause gearbox High torque, damage reasonable angular speed
DFRobot FIT 0441	Cheap powerful There is a gearbox 19.900 and high torque in the motor that and power with a could be damaged incremental by human steering encoder
Hudson - Brushless DC Servo Motor M-3432P-LN-08D	High torque, has Expensive 362.00 high precision encoder, No gear box, outrunner motor creates large torque.

I look up in an article *Steer-by-Wire Control System* by Adem Kader. He talked about how he implemented a steer by wire system and he used a low rpm high torque brushless DC motor connected to the steering wheel and a actuator with higher force to steer the car. Also I advised Chris Anderson who I worked with during the summer on another Autonomous Robot Car project. He is the COO of KittyHawk, a friend of Jack Silber man, our sponsor. He believes that if we want human input as well as computer input it is for the best to have a Brushless DC motor without gearbox or we need a high gear ratio gearbox that slows the Brushless Dc motor and increases torque and also make sure the steering rod will be tightly fixed with gears assembly. After getting their suggestions I believe the third choice should be the best to fit.

Reference

What lies in the shadows? Safe and computation-aware motion planning for autonomous vehicles using intent-aware dynamic shadow regions
https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=8793557

Modification of vehicle handling characteristics via steer-by-wire

https://ieeexplore.ieee.org/abstract/document/1522236?casa_token=niI7CQfxv04AAAA A:6xjecqC7s7XU9xpO1Mr11x9DFmgeMYoBhST6MWAedfqnh1IrAQ5X2-H-HvH3beGY1 pPy0bS5

Steer-by-Wire Control System

https://www.swarthmore.edu/sites/default/files/assets/documents/engineering/AK_Final. pdf