LazerKart

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***Abstract* — This project is the complete retrofit of a recreational go-kart with laser tag equipment, computerized motor control, and various other sensors. The goal is to add a whole new level of fun to an already enjoyable activity. By integrating infra-red laser tag type equipment with the kart, racers will be able to tag each other as they race around the track. By attaching computer controlled servos to the kart's engine governor, our system is able to temporarily idle the engine when the racer is 'tagged' or temporarily boost their speed as the game allows.**

***Index Terms* — Embedded System, IR communication, Photodiodes, Servo Actuated Motor Control.**

I. Introduction

Since the 1990's, many millions of people who play video games have played a game from the Mario Kart series produced by Nintendo. The game pits up to 8 go-kart racers against each other to see who can finish the race first, with one caveat, each car can obtain randomly selected items placed around the racetrack that can help them win the race. The question that was asked amongst the group was "How fun would it be to do this with real go-karts?" So, the main objective of this project, called LazerKart, is to produce a similar experience to the Mario Kart video game that would immerse the driver in a battle race that would require skill and a little bit of luck. The overall design would be relatively inexpensive, could be applied to existing go-kart venues, and would try to capture the imaginations of those who have played the game along with those who haven't.

The LazerKart concept involves multiple go karts, a go kart racetrack, and the system integration. The most basic implementation will allow the driver of a Kart to obtain an "item" by driving over a colored marker which is located on the track. Once driven over, a microcontroller on board the kart will randomly generate an item and illuminate a "ready" light. When pressed, a trigger button located on the steering wheel will activate the acquired item. Initially, the item could be an Infrared "laser cannon" that cuts a target karts' throttle down to idle for several seconds or a turbo booster that briefly accelerates the kart beyond its normal top speed. A separate color marker will automatically trigger the turbo booster. With pickup zones and boost zones placed strategically around the track, newer tricks and tactics will allow for the use of more of the track surface.

In order to make LazerKart realizable, a low-power distribution system and microcontroller must be feasibly employed to sustain an optical sensor sub-system, an IR emitter/receiver subsystem, a throttle control subsystem, and still have headroom for additional components heretofore unmentioned. Each of the main systems and subsystems must undergo extensive research, design and testing. It must be able to operate outside in broad daylight, at night, in varying daily weather and all the while demonstrate a fun, balanced gameplay mechanism that makes the experience worthwhile. All testing will be done outdoors on asphalt at a car lot using a temporarily donated go-kart from The Fun Spot in Orlando, FL.

As the basic LazerKart implementation becomes fully functional and passes all tests, other subsystems and extensions of existing systems will be designed to enhance the overall experience. The plans for this next stage of development include adding sound effects to supplement the item usage, an LED display (segment or dot-matrix) to replace the ready light, Zigbee wireless networking to allow for more interesting items and to maintain leaderboards, RGB LED accessory lighting that visually enhances the game, and a handheld laser cannon for two-seat go karts, among others. The functional block diagram is show in figure 1.

II. HARDWARE SYSTEM DESIGN

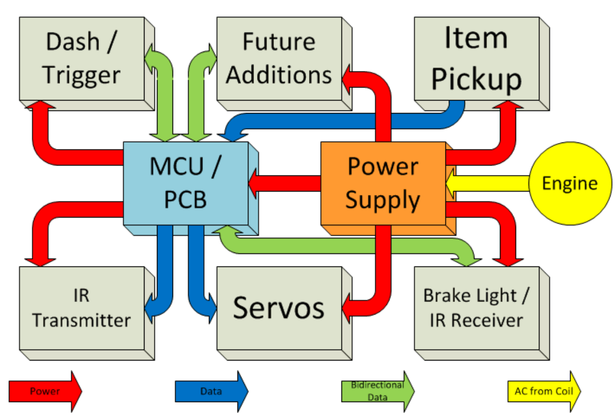

Figure 1: Functional Block Diagram

A. Power System

One of the project's key features is that all electronic systems are powered using the AC coil generator on the Honda GX270. The motivation is to eliminate the need for additional maintenance and the high cost associated with the use of batteries. The generator is rated to produce 50W of power and a total current output of around 3A, limiting the amount of electronics that can be used. Given the number of subsystems that can be applied to the project, the power system is designed to accommodate a range of possible load and current requirements with the use of LDO linear regulators. Linear regulators were chosen for their versatility, low cost, reliability, reparability and the minimal number of external components needed in comparison to most switching regulators.

The power system design for LazerKart focuses on delivering the necessary DC voltage and current required by each component and subsystem. The subsystems include the weapons pickup 1W UV LED, MSP430 controller, TSOP4856 IR transmitter, multiple user dash LEDs, HS-311 CUT and BOOST servo motors, 2 1W brake light LEDs along with any of the optional modules considered such as the LED accessory lighting and in game sound effects.

One of the primary challenges faced when designing the power system was conditioning the AC signal produced by the generator on the Honda. The amplitude and frequency of the AC signal changes with respect to the throttle position, making it necessary to choose components that can handle the range of possible voltage values while providing sufficient current when all subsystems are active or a *worst-case-scenario.* These variances are shown in figure 2. The AC output signal produced by the coil is being conditioned to a steady DC value using the GBL005 full-wave bridge rectifier and a 2200 µF electrolytic smoothing capacitor in parallel with several smaller capacitors to improve transient response and minimize higher frequency interference. These caps will feed directly into several series 1N5404 power diodes that are being used to further reduce the voltage coming off the coil to a more reasonable value that will be used as the input to the regulators. Once the ripple voltage was obtained it was used as the input to the voltage regulators to provide steady values of 3.3V and 5V along with currents between 250mA to 2A. The LDO regulators used are the adjustable LM317HVT, and fixed output UA78M33C and LM7805C.

Throttle position	Idle	Pedal-to-the-metal	Boost! (redline)
Vrms	9.34 Vrms	19.26 Vrms	23.03 Vrms
VDC (across cap)	22.35 V	43.6 V	47.2 V
RPM	1490	3220	3600
Tp	40.2ms	18.6 ms	16.6ms
Frequency	24.83 Hz	53.67 Hz	60Hz

Figure 2: Signal Differences at Different Throttle Levels

The LM317HVT regulator was chosen primarily due to the large input-output voltage differential rating of 60V along with the capability of sourcing up to a 1.5A current continuously. The voltage seen across the 2200 µF smoothing capacitor while the throttle is all the way open (normal operating condition) is about 48VDC and only 22VDC while the kart is at idle. The power diodes are connected to the VIN pin on the LM317HVT adjustable regulator. The output pin on the adjustable LM317HVT is set to around 15VDC giving a maximum input-output voltage differential of about 28V and a minimum input-output voltage differential of about 7V. To accommodate such large Vin-Vout values the power system uses the LM317HVT adjustable regulator as the primary regulator while the LM7805C and UA78M33C are secondary regulators connected in series to the adjustable regulator to share the voltage differential and heat dissipation among the two. Since the total current output capability of a regulator goes down as the voltage differential increases, each subsystem will be powered by its own pair of series regulators that will in turn be in parallel with the other module's regulators to reduce the current draw for any given regulator, improving the efficiency, extending the life of each component and allowing for a modular system that can be repaired independently if needed.

The expected power consumption of each module can be seen in figure 3 below.

Module Part	Supply Voltage	Operating Current	Power
Brake light LEDs	5.0V	660mA	2W
Dash LEDs	5.0V	200mA	1W
IR Rx TSOP4856	5.0 V	1.5 mA	7.5 mW
IR Tx TSAL6100	5.0 V	200 mA (surge @100us)	1 W(surge)
Pickup sensor UV LED (2)	5.0V	40mA	0.2W
User trigger	5.0 V	20 mA	0.1W
MCU MSP430G2553	3.3 V	230 uA	0.8mW
Servo motors HS-311 (2)	5.0 V	600 mA	2W

Figure 3: Power consumption for core modules

When the power consumption of each module is added to the power dissipated as heat on the regulators along with resistors and other miscellaneous parts the total power consumption is nearing the generator's total power production of 50W. To remedy a possible power shortage, the module's total current draw is capable of being reduced or more specifically the brake light and pickup LEDs current draw, to pull the total power required down.

B. Item Pickup

The item pickup subsystem is intended to detect the presence of different colored indicators on an asphalt road or go-kart track. For the purposes of LazerKart, only two colors will be necessary to detect: One for a random item (red) and one for a dedicated turbo boost (green). A simplified block diagram of the subsystem shown in figure 4 is presented to give a general idea of the process.

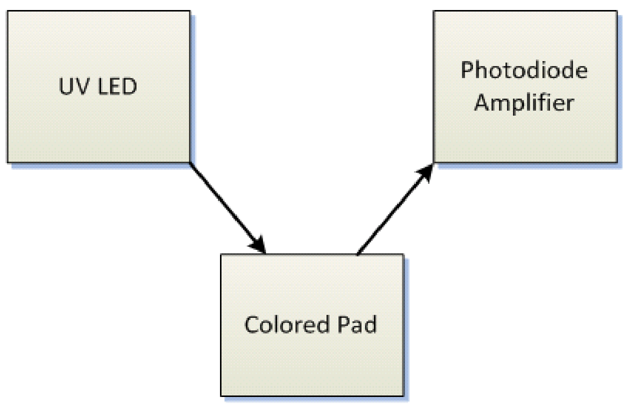

Figure 4: Block Diagram of Item Pickup Subsystem

The primary obstacles that were overcome in the design process were the following:

- Illuminating the indicators enough to acquire a signal
- Designing an efficient circuit to distinguish between colors
- Detecting consistent color signals in the presence and absence of sunlight

The first issue that was resolved was being able to illuminate the colored indicators enough that their radiant energy would generate a respectable current through a photodiode. A feasible solution was to implement a UV led as a light source illuminating the ground, and to use fluorescent colored squares made of poster board for reflection. The fluorescence of the squares under UV light laid the groundwork of the color detection scheme and is much simpler than integrating a more complicated camera system or color sensor IC. The UV light source is a ProLight 1 Watt UV LED with a dominant wavelength of 400-410nm and radiometric power of over 475mW, which is more than 15 times more power than a standard 5mm UV LED**.**

With respect to determining an efficient way to distinguish color, several methods were proposed, but the best solution (which required only one pin on the MCU) relied on a Trans-impedance Amplifier (TIA) and Analog-to- Digital Conversion. The TIA converts the current input from a Vishay TEFD4300 PIN photodiode into a voltage on the output, which in turn is fed into an analog input pin on the MSP430. The MSP430's Analog-to-Digital (ADC10) core repeatedly samples the voltage on that pin and triggers an interrupt when the voltage breaches a certain threshold. That threshold was determined empirically to be about 1V. The reason for this is that the photodiode's spectral sensitivity is practically linear in the visible light spectrum, and the TIA feedback resistor was chosen such that the two colors, green and red (~ 525nm and 650nm, respectively), produced output voltages greater than 1V, with red being roughly 4/3 greater than green.

Since gas-powered go-karting is primarily performed outside, sunlight will be present and will reach underneath the go kart and hit the Photodiode. The interference of ambient sunlight tends to generate unwanted noise current out of the photodiode and can trigger false readings on the ADC10. The reason is that sunlight could add as much as 500mV DC to the signal output and the difference between colors (voltage-wise) is within that tolerance. At this point, the design was expanded to incorporate modulation, ambient light rejection (DC-blocking high-pass filter), and demodulation. Both the UV LED and the photodiode are facing down towards the ground. A TI NE555 timer is configured to generate a 56kHz square wave output which switches a logic-level n-channel MOSFET. Connected to the drain of the MOSFET is the UV LED, which is now flashing at a rate of 56 kHz. The pulsed light that reflects off of the ground is incident upon the photodiode. The TIA then amplifies the incident light signal and outputs into an active high pass filter to reject any low frequency and DC light. The HPF output feeds into an envelope detector, which demodulates the signal into a DC value that is finally sampled by the ADC10. The differences in signals generated by the different colors are shown in figure 5.

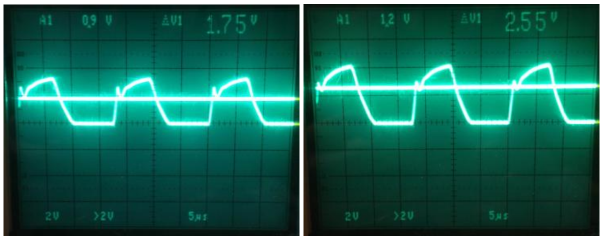

Figure 5: Side-by-side comparison of green color voltage (left) and red color voltage (right) output. In each screenshot, the periodic waveform is the output is measured at the input to the envelope detector stage, while the 'DC' value is at its output.

C. PCB

The MSP430 will be mounted on a printed circuit board. The pins on the MSP430 that are actually utilized by this system will be connected to wire terminals at the edges of the board for connection to the various other modules. The MSP430 will be able to read and control many of the other features directly, but the infrared transmitter and the brake lighting system will require more power than the MSP430 can source from a single pin. Therefore, the printed circuit board will also have a MOSFET connected to the IR transmitter. The brake light assembly will have its own 5 volt power supply and on-board MOSFETs for current control. The MSP430 itself will be mounted in a 20 pin DIP socket that will be solder to the printed circuit board. Mounting the controller in a socket instead of soldering directly to the board will ease in programming, debugging, and upgrading the system later. A diagram of the PCB has been provided below in figure 6.

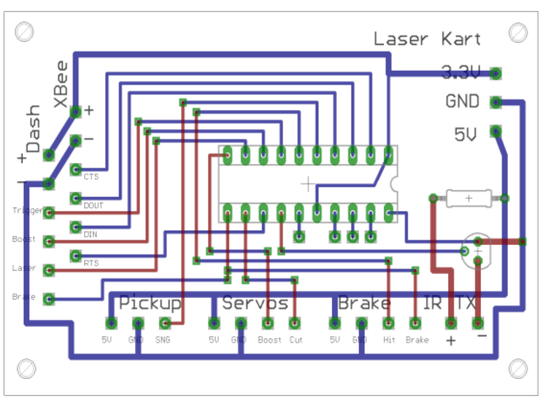

Figure 6: PCB Layout

D. Brake Light

The brake light enclosure houses two 1-Watt LEDs capable of sourcing 350mA, a TSOP4856 IR Receiver Module, and associated components. The brake lights themselves will illuminate in 2 ways: when the rider engages the brake pedal, a simple contact switch closes the circuit, or if a hit signal is received by the microcontroller, an N channel MOSFET activates. The brake light is attached to the IR system mounting box located above the driver. Fun Spot, the project sponsor, was extremely interested in including a brake light into the project, as it adds an extra layer of safety to their karts.

E. IR System

The IR System is integral to the game play aspect of the project. In order to facilitate more interaction between the racers, and to enable more opportunities for passing, the IR system allows the racer to tag the other karts on the track. A successful tag will cut the engine of the kart ahead of you, allowing you to pass. We have chosen to pair the VISHAY TSOP4856 IR receiver with a VISHAY TSAL6100 high power IR emitting diode. This combination is ideal, due to the matching characteristics of the IR light wavelength that the components operate most optimally at, approximately 940nm. This is shown in figure 7.

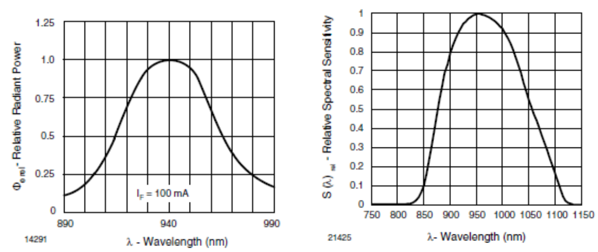

Figure 7: Transmitter and Receiver wavelength pairing [1] [2]

The Transmitter LED is center mounted in a ¾ PVC pipe. In order to produce hits at longer distances, and to make it more challenging to tag the kart at shorter distances, it is necessary to focus the IR light with a lens. The outside diameter of a ¾ pipe is 1in, or approximately 25mm. In selecting the lens we needed to take into account that the TSAL6100 has an angle of half intensity of ± 10°, which for a 25mm lens gives us our optimum focal distance of 55mm. Using a double convex lens with a diameter of 25mm and a focal length of 55mm has given us triggering ranges in excess of 150 feet, more than adequate for our uses.

The Receiver circuit is mounted in the brake light assemble and consists of the receiver, whose output is connected to an International Rectifier IRLR024N MOSFET. This particular MOSFET was chosen for its fast switching time, and low gate threshold voltage.

Testing revealed that this was necessary to achieve the desired results.

The entire IR system is attached to the kart above the drivers head. This was done in order to match the level of the transmitter and receiver. The driver will not be able to independently control the direction of the transmitter, so it is imperative that these two units be level with each other. This allows a hit to be made, regardless of distances of the karts. This module is shown in Figure 8.

Figure 8: IR System Mount

F. Dashboard and Trigger

The concept behind the dashboard is straight forward and relatively easy to implement. The idea is that there needed to be some kind of obvious indicator of what is occurring in the game at any given time that can be easily interpreted by the driver of the go kart. To do this we designed the dash to display three different colors, red, blue and green, for the different functions of the game. More specifically, when the LazerKart passes over a pickup sensor on the track the dashboard flashes the blue and green LEDs to indicate that an item was in fact detected (blue light indicates a laser and green light indicates a boost). The blue and green LEDs alternate back and forth until only one light will remain on, indicating that they have acquired either a boost or a laser. That color will remain on until the driver pushes the trigger which will then either cause acceleration or fire the laser at their opponent. Once the trigger has been pushed the blue and green LEDs will remain off until the LazerKart goes over another item. The third color red will only light up when the user is hit by an opponent.

The dashboard uses a total of 9, 15mA LEDs in parallel, 4 of which are multi-color green/blue LEDs and 5 red LEDs in an "X" configuration. Each set of colored LED's cathode is in series with an LU024N HEXFET power MOSFET, of which the gate is connected the appropriate pins on the MSP430 controller to complete the circuit to ground when the dash is supposed to light up. The trigger is simply connected to and output pin on the MSP which is floating until the trigger is pulled and the circuit is completed to an input pin on the controller that is waiting for a signal from the Driver to activate the transmitter or the boost servo motor. Figure 9 shows an image of the dashboard with all the LEDs lit.

Figure 9: Kart Dashboard

G. LED Accessories

The LEDs will be placed in various locations on the karts, including on either side of the driver and around the roll bar above the drivers head. The programmable LEDs will be controlled by either the available pins on the MSP 430, the use of I2C or an entirely separate Arduino MCU depending on the requirements, time and budget constraints of the project. The LEDs will perform different lighting displays depending on the event occurring in the game. For example, when a driver is hit by an opponent, the LEDs will flash red for a few seconds, giving the effect that their kart is malfunctioning or if the driver fires their weapon the LEDS will display a cascading effect from back-to-front as though the weapon is being discharged.

H. Microcontroller

To control our system, we used an embedded microcontroller. The microcontroller reads from several inputs and controls several outputs. Information coming in to the microcontroller includes the voltage from the item pickup sensor, the driver's trigger, and the IR receivers.

The microcontroller will also control several outputs. These include dedicated pins to control the Item Pickup

LEDs, the IR “laser”, brake lights, hit lights, and to control two servos.

A core feature of the LazerKart system is the ability to electronically and programmatically control the engine. There are three states that the system will need to select from. First is the normal state where the engine speed is completely dependent on the driver's input to the gas pedal. Second, when the kart is “hit” by a “laser”, the engine will need to be forced to idle for a short period of time. Finally, when a “boost” is activated, the engine will need to be allowed to briefly run at higher power than is normally allowed. The Honda motors on these karts are equipped with a governor that allows for engine power modification. When rotated clockwise, the engine throttle is set to the idle position. When rotated counterclockwise, the engine throttle is opened further than normal. This arrangement lends itself to being controlled by two servos attached to either side of the governor.

To meet these input and output requirements, we selected the Texas Instruments MSP430G2553. Its features are summarized below.

TI MSP430G2553IN20
Frequency: 16 MHz
Flash Memory: 16 KB
SRAM: 512 bytes
IO Pins: 2 Ports, 8 Pins/port
Timers: 2x 16 bit Timers
USCI_A: 1 UART
USCI_B: 1 I2C/SPI
ADC: 8 Channels, 10 bit ADC
Package: 20 pin DIP
Price: $2.79 from Digikey.com

I. Testing Hardware

To aid in development, troubleshooting, and final testing, we have developed two stand alone infrared systems that will allow us to simulate the IR transmitter and receivers of other karts. This was a necessity because so much of this project is about interacting with other karts.

- Receiver Box

  To test that our IR transmitter is generating the correct signal, we built a standalone IR receiver box. It contains a battery pack and a simple circuit consisting of an IR receiver identical to the one on the kart, a large LED, a power switch, and a MOSFET to source power to the LED. When the box is turned on, the LED will glow until a 56 kHz IR signal is seen by the receiver. When the LED turns off, we know the receiver is sensing the IR signal.

- Transmitter Zapper

  The other IR feature that needed extensive testing is the IR receiver on the back of the kart. To facilitate this, we re-purposed a plastic toy dart gun into an IR transmitter. To ensure the receiver on the kart responds predictably, we built into the toy gun the same components used on the kart's IR transmitter. We used the same IR diode connected to the same MOSFET and driven by an MSP430 using very similar code. The optics were also identical. When the trigger on the toy gun is pulled, as switch is closed that tells the MSP430 to active the 56 kHz pulse width signal. This signal drives the MOSFET which in turn controls the current through the IR diode.

III. SOFTWARE SYSTEM DESIGN

The LazerKart system will be controlled by the MSP430. Because the events that make up the game will happen relatively infrequently, the software is largely interrupt based. It will use global variables to keep track of interrupt flags, items picked up, items used, and general counters.

The Main loop on the software program increments an item counter. Changing the value of this counter every clock cycle allows for randomized item pickup.

As the different sensors and modules of the LazerKart system detected events, they will trigger interrupts and the associated interrupt service routine. These are summarized here. Figure 10 shows the programming flowchart.

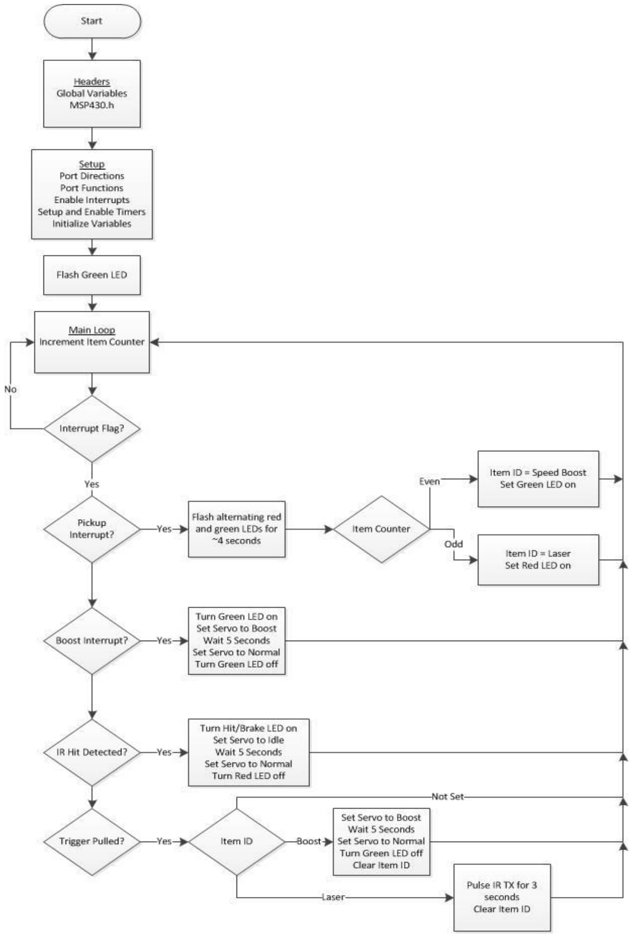

Figure 10: Software Flowchart

A. Item Pickup

The photo diode detector is connected to the MSP430 on an input pin. The voltage on this pin will vary based on the amount of light the photo diode is sensing. The MSP430 has a 10 bit analog to digital converter built in that we will use to read this voltage and call the Pickup sub-routine when a voltage is detected that corresponds to passing over an item pickup pad. Once the pickup routine has been called, the code will check the value of the item counter from the main loop. It will then flash the LEDs several times and then settle on the appropriate item. That LED will remain illuminated and the ready item variable will be updated with that item. The software flowchart for the pickup is shown in Figure 11.

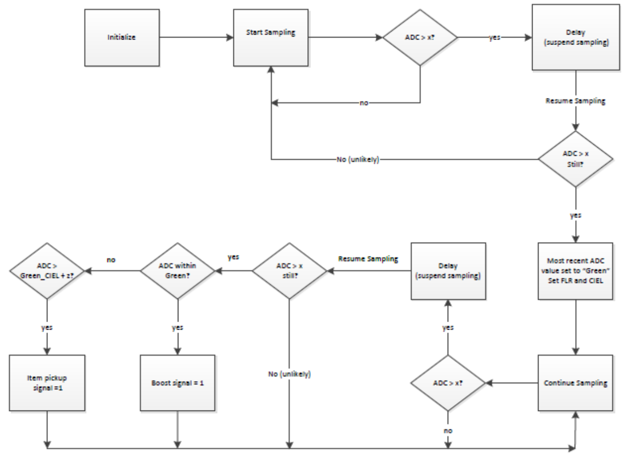

Figure 11: Item Pickup Color Calibration

B. Hit Detected

When the IR receiver detects a signal from another kart, the kart has been "hit" by the "laser". The circuitry in the Brake Light will cause the Hit pin to go from 0 volts to 3 volts. This 3 volt input to the MSP430 will trigger the Hit interrupt routine. The MSP430 will then illuminate the brake lights and the dashboard Hit lights, as well as command the Hit Servo to rotate to close the throttle to idle for 5 seconds. After 5 seconds, the Hit Servo will return to its neutral position and normal speed will resume.

C. Boost

When the boost detector has triggered an interrupt, the Boost subroutine will begin. The green LED will be turned on and the Boost Servo will rotate to command full throttle for 5 seconds. This is about 10% more power than is normally available to the driver. It makes for a fun acceleration and a few MPH increase in speed.

D. Trigger Pulled

Pulling the trigger will trigger the ISR from the trigger pin. This portion of the ISR will check the status of the ready item. If there is no item ready, the interrupt will be reset and the main loop will resume. If the ready item is 1, the boost routine will be called as described above. If it is 2, then the IR transmitter will activate. This is accomplished by using the built in Timer to generate a 50% duty cycle PWM signal at 56 kHz on the IR Tx pin of the MSP430. This signal turns on and off the on-board MOSFET at 56 kHz, thus supplying the IR transmitter with the appropriate signal.

IV. CONCLUSION

The culmination of this project, LazerKart, lies in the harmony of all subsystems and graceful execution of all gameplay mechanics. Through exhaustive research, extensive testing, and careful production, LazerKart is expected to be a stellar product that exceeds all expectations. The engineering team will bring a multitude of technologies together for a design that will not only impress those who are technically inclined but will also bring a smile to the average person who knows little of the inner workings involved.

Everything from wireless communication, embedded microcontroller programming, and power distribution to LED light displays and sound effects can potentially be employed in LazerKart, for a demonstration of a vast understanding of a multitude of technologies. The implementation is two-fold: not only will there be an academic reflection in LazerKart, but also a possibility for a marketable platform that could be low-cost and easy to maintain. The collective group feeling about the potential for LazerKart has been nothing short of positive and passionate, which has thus far helped to drive the progress in developing the concept further without getting discouraged.

With pre-production well under way, as far as prototypes and working proof-of-concept demonstrations, LazerKart is on schedule to be swiftly developed and completed from connectors and PCB to brackets and enclosures by the end of Fall 2013 for not just one, but perhaps 4 or more go-karts.

ACKNOWLEDGEMENT

The team members would like to thank our sponsor Fun Spot ™ for lending us a go-kart, the CECS faculty for their dedication to learning, and our fellow students for being great sounding boards for our ideas.

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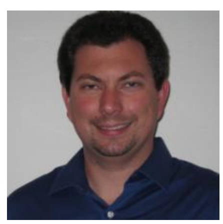
[2] VISHAY SEMICONDUCTOR “High Power Infrared Emitting Diode, 940nm, GaAIAs/GaAs” (product data sheet) March 13, 2013 from http://www.vishay.com/docs/81009/tsal6100.pdf

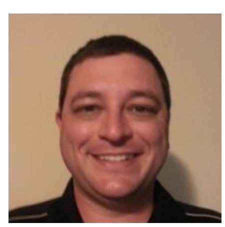
BIOGRAPHIES

Evan Brown will be graduating with Cum Laude honors distinction from the University of Central Florida in December 2013 with a Bachelor’s of Science in Electrical Engineering. While at the University of Central Florida he has completed graduate level coursework and is a member and recipient of scholarship awards from the NACME organization. He is also a member of The National Society of Leadership and Success, Sigma Alpha Pi. After graduation he plans on being involved in Hardware Design and possibly furthering his education in graduate school.

Ryan Dixon will be graduating from the University of Central Florida in December 2013 with a BSEE and a CS minor. He has completed graduate-level coursework in full custom VLSI design that resulted in the fabrication of a reconfigurable LFSR. He was also part of a team that competed in the NYU Poly 2013 CSAW Embedded Systems Challenge. He desires to be involved in the electronics industry, bridging the gap between Software and Hardware Design.



Tom McClelland will graduate from the University of Central Florida with a Bachelor’s of Science in Electrical Engineering in December, 2013. Additionally, he holds a Bachelor's degree in Aeronautics from Saint Louis University. While at UCF, he was active in the Robotics Club and did internships at Siemens Energy, Earthrise Space, Inc., and SpaceX. Following graduation, he will join SpaceX at the Kennedy Space Center as a Launch Engineer.



Adam Sefchick will be graduating from the University of Central Florida with a Bachelor’s of Science in Electrical Engineering and a minor in Technological Entrepreneurship in December, 2013. While at UCF, he completed graduate level coursework in full custom VLSI design. Following graduation he intends to work in the industry in a client facing role, and to return to graduate school for his MBA.