Intro (These headings can be used to navigate through the doc)

The Institute of Electrical and Electronics Engineers (IEEE) hosts a yearly hardware competition at its Southeast Conference (SECON) for students to compete in. Tennessee Technological University has competed in the IEEE SECON hardware competition in the past but has often had issues undiscovered until the actual competition.

The 2025 competition rules and limitations will be explained in detail below but, in short, its challenge takes place over 3 minutes and involves collecting and separating two types of 40mm icosahedrons (astral material) randomly distributed on the field. Geodinium, one type of astral material, is slightly magnetic and heavier than Nebulite, the other type. The challenge is to sort these two types of astral material into two designated containers, and then bring those containers to a randomly chosen area on the board. Additionally, there is a dark roofed “cave” area with further Geodinium and Nebulite. The board is relatively simple with few obstacles beyond the containers and astral materials to navigate around, and as such, the goal is to focus on reliability followed by an extensive testing period. There are two types of matches, qualification matches in which the eight teams with the highest scoring qualification matches, and elimination matches where two teams directly compete against each other’s scores.

The point distribution greatly rewards being able to correctly and reliably sort Geodinium and Nebulite into their corresponding containers so, by reliably gaining these points and unreliably gaining others, performance can be optimized for both the qualification matches and elimination matches.

Problem

Motor Control

During the competition, the robot will need to move quickly to collect as much astral material as possible within the allotted 3 minute timeframe. Therefore, one of the focal points of previous design teams for the robot was to ensure precise motor control for efficient power usage and movement while also protecting other subsystems from disruptive effects produced by the motor.

The motor control subsystem is formally known as a motor drive and can include the following components: a microcontroller (MC), motor driver, motor, power supply, and specific components for noise reduction and circuit protection [Motor Driver Fundamentals]. The motor microcontroller carries the signal commands from the master controller for the designated motor to operate as required. However, the power that the MC needs to function is not enough in comparison to what the motor needs. Therefore, it is essential to have a component that can step up the current from the MC to the motor. This is the purpose of the motor driver. The driver also provides voltage regulation for the higher threshold of the motor, precision control for speed and torque, overload protection, and noise protection for the circuits involving low-power logic control [Motor Driver Fundamentals]. Regarding the motors themselves, the team that worked on the previous robot base used DC motors due to their increased control capabilities and starting torque in comparison to AC motors. However, they were concerned with the back electromotive force that moves in the opposite direction of the motor spin. The back emf can interfere with low-power, highly sensitive logic circuits. This problem is also present when the motor stops or quickly slows down [Back-EMF]. During the match, the robot will be required to quickly move across the area of play and collect astral material automatically. The robot will need to stop and start again numerous times as it makes its way around the field. The back emf generated by continual stopping and starting of the motors would be harmful to the control circuitry, generating noise. It is critical to reduce this emf noise generated by the motor as much as possible for optimal communication between the controllers and mechanisms.

Sensors for localization and navigation

For the competition, the robot will need to know where it is with respect to its goal and its boundaries. There are multiple items that will help the robot with navigation and localization. These items include walls and April Tags as shown in Figure 1. The walls of the arena, 3.5 in. tall, are relatively small compared to the maximum size of the robot (12 in.) and the height of the cave walls (24 in.). One April Tag is placed on each of the four sides of the game arena. Three of the tags are outside the cave, while one is inside the cave. The tag inside the cave is across from the entrance. The tag across from the cave tag is for designating the correct rendezvous pad to deliver the containers to. To the right of each of the containers is a tag.

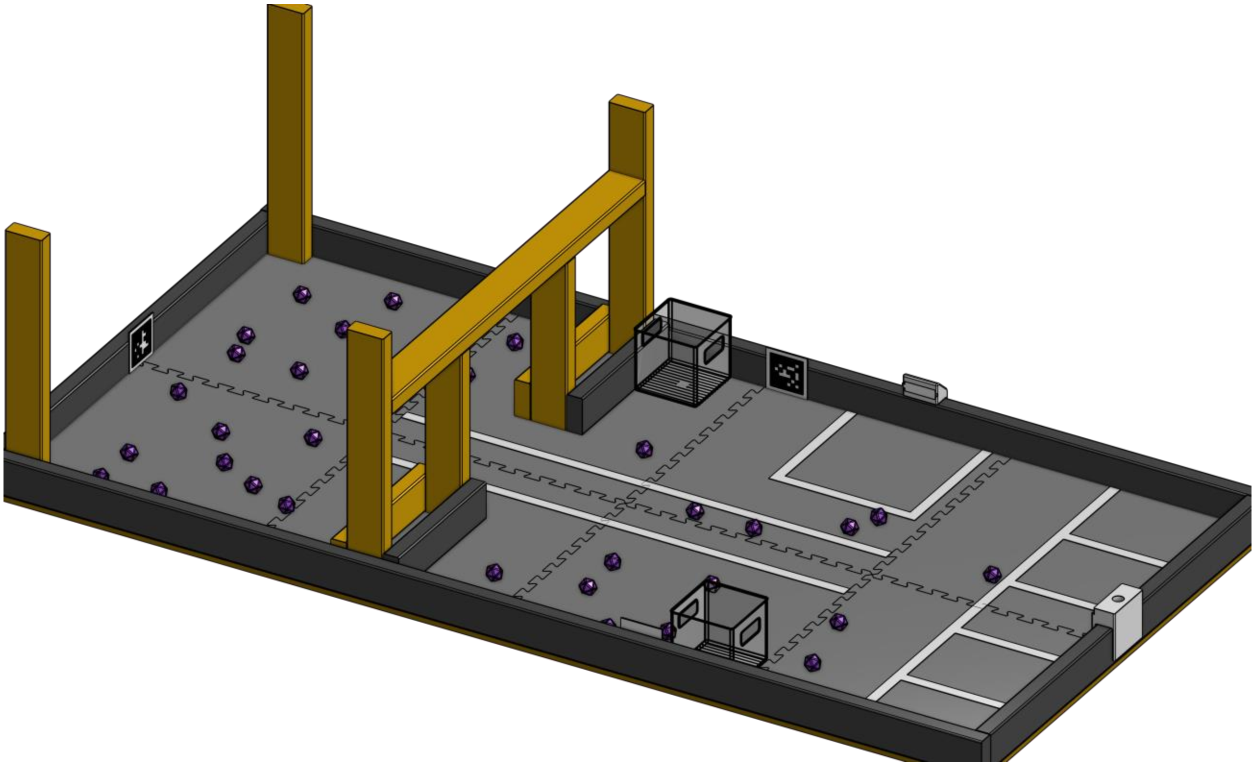


Figure 1 shows the game field without the cave covered [source GM2].

Navigation and Master Control

The robot must take in data from its sensors, keep track of its own location, determine the location of the astral material around it, plot a path taking into consideration certain static objectives (such as entering the cave, and the containers for the astral materials), send the corresponding signal to the motors, and then automatically shut down after three minutes.

Object and Line Detection

During the competition the robot will need to be able to detect the white lines that denote the starting area, the 5 telemetry zones, and the path in and out of the cave, and interpret the lines in a useful way pertaining to the competition. The robot must also be able to detect the astral material and the shipping containers. The robot must be able to detect the white lines, the astral materials, and the shipping containers in both illuminated and dark environments. The robot must be able to mark and remember the locations of the shipping containers, the astral materials, and the white lines so that it can plan an efficient path to collect the astral material and place it in the shipping containers.

Specifications – Breakdown

Motor Control

The Mining Mayhem Game Manual 2 specifies that there is a 3 minute timeframe for the robot to operate and collect points. After the 3 minutes, all robot units, portions of the robot with individual autonomy or self-actuation [source GM1], must cease operation and no game element positions can be disturbed, as per rule G07. It is suggested that the robot has an automatic stop that is set to trigger within three minutes of starting rather than a manual stop, which has the potential for user delays and other scoring complications. Therefore, the motor control system must be properly synched with the master controller to safely and efficiently stop the functionality of the robot mechanisms in play.

Regarding the specifications for the circuitry, rule R13 states that the robot should account for some natural background interference. Therefore, the reduction of back emf from the motors will only reduce the amount of noise, not eliminate it. The electrical design will need to have protection in place for a variety of potential sources of noise beyond what is already generated from the robot.

Professional standards for regulation of motor control design and general engineering practice should also be considered. The standard IEC 60204-1 deals with requirements pertaining to electrical supply, electromagnetic compatibility, emergency stop, and control circuit protection. The power-based and electromagnetic interactions of components in the motor control subsystem will need to adhere to this standard [safety of machinery].

Sensors for localization and navigation

The sensors used to localize the robot need to be able to detect the walls of the arena, April Tags, and the spatial geometry of the robot. The robot will need to know the limits of where it can be and where within these limits it is located. The walls set a hard limit on where it can be. Along with the walls, April Tags can be used to locate itself with respect to where it expects to be. Furthermore, a sensor will be used to determine its geometry in the arena.

The sensors are not allowed to use visible light laser or strobe lights, according to the rules. The sensors will need to fit with the cubic foot limitations and have a low power consumption. The voltage needed to use the sensors needs to be less than thirty volts. All sensors to help the robot navigate and locate itself should be interfaced with one or two microcontrollers [source GM1].

Navigation and Master Control

The robot must act fully autonomously. No external commands or signals may be used to manipulate the robot's actions [source game manual 2]. Additionally, the robot must be able to stop immediately via the usage of a clearly marked emergency stop button. The robot may start via a sensor's recognition of a start LED or via the manual operation of a clearly marked start button. The robot must autonomously coordinate its subsystems to achieve points via tasks designated in the IEEE Game Manual 2. It must do this between three to six times. The navigation and master control subsystems must take data from the sensors and turn them into actionable signals for the motors to utilize.

Emergency Stop

As stated in the game Rules R04 [insert reference], each robot competing in the match must have a clearly marked emergency stop button/switch. This is also a safe method of ethics to follow for autonomous machines as stated in NFPA 79-10: NFPA 79 Section 10 outlines Emergency-Stop system Requirement for industrial machinery. The Robot's E-stop will be based on the code identified in the reference. [insert reference]

Object and Line Detection

The robot will need to be able to detect small and large objects in both light and dark environments. It will also need to retain knowledge of these objects and be able to plot a course across the game field to collect these objects and then place them in shipping containers in an efficient manner. The robot will need to be able to detect and correctly interpret white lines on a dark background, this task will also need to be able to be performed in both light and dark environments.

Constraints – Breakdown

The robot shall be able to detect the walls of the arena, walls of the cave, and cave entrance.

The robot shall know its location within 2 in. (5.08 cm).

The robot shall have an autonomous navigation system that controls movement.

The robot shall turn left and right 360 degrees and move forwards and backwards based on external sensor inputs and its internal localization systems

The robot shall read April Tags.

The robot shall fit within a cube with 12 inches per side.

The robot shall have a user manual that explains functionality and design intent for each subsystem.

The robot shall be able to detect the white lines on the game board.

The robot shall be able to detect, identify, and localize the astral material and the shipping containers.

The robot shall be able to detect both objects and lines in both light and dark environments

The robot shall have protective measures against back EMF and other sources of noise interference.

The robot shall contain a modular battery that supplies power to the microcontroller and motor of the machine.

The robot shall sustain power of 30V maximum as correlated to the Game Manual R16 for at least 1 hour and be rechargeable for continuous use.

The robot shall have at most 2 power buses for the efficiency of both the motor and microcontroller circuits that are used to process.

Survey of Solutions – Breakdown

Motor Control

In order to adhere to the constraints as given from IEEE and as required from the physical electronics, an ideal solution for motor control would be a self-regulating, efficient, and protective system that can reduce adverse interference effects and relay commands as quickly as possible. To reduce the noise generated by the motors and environment, there are several techniques in use that can be applied to the robot, including PID tuning, filtering, and shielding [Back-EMF].

PID tuning is a method that involves continuous monitoring of the current state of the motor and adjusting the aspects of that state as required. A proportional control will have a threshold speed and fluctuate over and under that speed. Integral control will monitor and change the difference between the threshold and the middle of the proportion ranges. The derivative control will monitor general change that occurs with the motor speed [PID Control]. In between voltage pulses as power is being applied to the motor, the noise that the decoder can detect comes from the back EMF. The decoder is then able to initiate changes based on the back emf reading. That way, if there is a drastic increase in speed and resulting back emf, the PID controller can regulate the speed and bring it back down, reducing the effect of the back emf on the control circuitry.

For the noise filtration method, a capacitor is often used as a short circuit for changing, high frequency currents, which will be present if the robot continuously starts and stops the motors. A single capacitor can be attached to the motor terminals to lower noise along the wires, but multiple capacitors connected to the motor terminals and the casing can act as a diverting path for exterior noise emanating from the motor into its environment. A note to keep in mind for this method is that ceramic disc capacitors must be used, as electrolytic capacitors can explode when used for this purpose [Back-EMF].

For shielding, the material properties of the exterior of the motor must be considered, as it should be made of metal and reflect or take in the radiated waves from the motor aperture [Back-EMF].

Even though the previous methods help reduce noise from the motors, there is still the environmental noise reduction that needs to be addressed. The patent “Noise reduction in integrated circuits and circuit assemblies” [Noise reduction patent] discusses a method that reduces digital noise in IC chips by shaping the noise to be condensed into a small set of frequency ranges, leaving the circuit to have more flexibility in the frequency ranges that it operates with. Another application that deals with noise reduction can be seen with Data Acquisition and test systems, with the following methods placing an emphasis on reducing coupled noise from external sources [DAQ noise]: cable shielding, using twisted pair cables, isolating signals, ground wires properly, organizing wiring pathways, and using anti-aliasing filters. Each of these methods can be implemented into the electrical design of the robot, and they should be considered for the efficiency of the autonomous communications and the safety of the equipment and surrounding environment.

Sensors for localization and navigation

According to the works presented in Modular IEEE Robot, there were two sets sensors used for localization and navigation. The Grove Ultrasonic Sensor is used for navigation. This sensor sends out a high frequency sound pulse, collects the reflected pulse, and calculates the time between the output and input [source orientation signoff]. The Adafruit LSM6DSOX + LIS3MDL breakout board is used for orientation. It can detect changes in linear and angular acceleration and has a magnetometer for detecting the Earth’s magnetic field [source location signoff]. A single orientation sensor is used while an ultrasonic sonic sensor is used on each side of the robot [source ex spec 14].

April Tags can be read easiest with a camera. An RGB-D camera can read in both color and depth. The tags have both color difference and depth difference; however, the depth difference is only 0.4 mm. Using the color difference should be easily implemented and the depth can be used to filter noise out of the background. The data read in from the camera will have to be carefully analyzed and filtered to be able to read the tag from multiple different directions and angles.

A CMOS camera would be better than a CCD camera for its size and power consumption but have a higher noise level [source intro cams]. Choosing a resolution to pick out the tags is decided by finding the farthest distance from a tag the robot will have to read and computing the size needed to tell the difference between blacks squares and white squares in the tag [source cam talk].

Navigation and Master Control

The particulars of the navigational and master control system will be dependent on the sensors, and exact mechanisms used to manipulate the game field. Currently, two sets of solutions have been explored as the most viable considering the time limitations regarding construction. The base modular robot mentioned previously uses an Arduino Mega, along with two ESP 32 microcontrollers attached to sensors. It uses a modified A* algorithm for pathfinding that can be adapted for the particulars of the competition. Upgrading the Arduino Mega to a Raspberry Pi would provide a considerable amount of processing power while mostly allowing continued usage of their programming. This upgrade would also enable the usage of computer vision and machine learning to enable the robot to detect objects more specifically, and potentially allow the usage of Apriltag-based localization. The usage of Raspberry Pi for computer vision is ubiquitous to the point of having a dedicated page on the Raspberry Pi organization's website. [source raspberry pi]. The usage of Apriltag-based localization would require more coding, as there is literature on landmark-based localization, but nothing as specific as AprilTag-based localization.

However, the Jetson Nano utilizes ROS and QR-code based localization has been achieved on ROS [source qr-code]. A Jetson Nano is also more powerful with AI-related workloads as it contains a graphics processing unit that supports CUDA and is designed for AI-related tasks [source jetson] whereas a Raspberry Pi does not. A Raspberry Pi might have difficulties using computer vision, processing navigation algorithms, and controlling sensors and motors even with ESP-32 microcontroller support. Making use of a Jetson Nano would, however, necessitate an overhaul of the modular robot base's code, and possibly even the discarding of it entirely. Anecdotal experiences from mentors and fellow students have depicted ROS as difficult to learn and fully utilize.

Object and Line Detection

The robot will need some kind of sensors fitting for the task of object and line detection, as of right now the leading candidate is an RGB-D camera. For line detection once input from the sensors is obtained then lines can be detected from the input image in 1 of 2 ways. The first method is the Hough Transform; the first thing to do is divide the image into a series of cells much like a grid, the Hough Transform uses the equation $\rho = r \cos(\theta) + c \sin(\theta)$[Hough Transform source], which transforms each point into ρ,θ space, now that the image is in polar coordinates, each point is represented as a sine wave, and each time the sine waves intersect represents a line that crosses both points, so if we add up all intersections in each cell the cell with the most intersections will correspond to the strongest line in the image. The convolution method involves placing masks over the image; a mask is placed over each pixel and by tracking how well the mask fits across each pixel for multiple pixels in a row using an edge tracking software we can detect if any lines are present. [Convolution method source]

The robot can also use the RGB-D camera for object detection. Object detection is a task in the ECE field that involves picking out objects from some image, classifying them and localizing them. Classification is what something is, a tree, a rock, a man, or anything else, it classifies the object into a category, for this step our project will be simpler than many object detection program as we only have 2 categories of objects to classify. Localization is where an object is, what is around it and what physical space it occupies. The are many ways to go about the task of object detection, most methods fall into 1 of 2 categories. 2 stage detection works in 2 steps, first a series of uniform regions are proposed called anchors, the anchors are then evaluated on how likely a relevant object is in that anchor, then put through the classification and localization processes. Some examples of 2 stage detection are R-CNN (Regions with Convolution Neural Networks) and Fast R-CNN. [Object detection source] [Fast R-CNN source]1 stage detection involves merging the tasks of classification and localization into a single pass, some examples of this are YOLO (You Only Look Once) and SSD (Single Shot MultiBox Detector). [Object detection source]

Experiments, Testing – Breakdown

The robot will know its location within 2 in. while traversing to ten points of interest in a row in both an open and closed arena. This will ensure that the robot knows its location while it is traveling from point to point and through the cave. If the robot's internal location does not agree with its actual location, landmarks such as the April Tags will have to be used to help orient the robot.

Additionally, if ROS is utilized, there are programs such as Gazelle which can simulate the operation of autonomous robots in a physics-enabled world. Extensive testing in Gazelle can aid in testing and developing subsystems before the robot is even finished.

Unknowns and Source of Risk

Unknowns –

- How other robots at the competition will score
- The collection and sorting mechanism (temporarily)

Sources of Risk –

- The arena at the competition being different than the one used for testing.
- Damages occurring at the competition necessitating field repair.

Measurements of Success -

This section will define the effectiveness or success of the constraints and specifications listed above. If the robot does not meet 5 of the listed constraints it will be considered a critical failure. Some of the specifications stated may alter as the project progresses, but this will be at the discretion of ultimately the customer on a case basis. The success of the robot will depend on the completion of the project within the course deadline and before the competition deadline. We hope as a team that this robot will serve as a solid foundation to other students who come across a similar task. Although the goals are set and it is desirable to fully realize them, there are alternative investments that are being made for future generations in the completion of this project.

Ethics and Responsibility

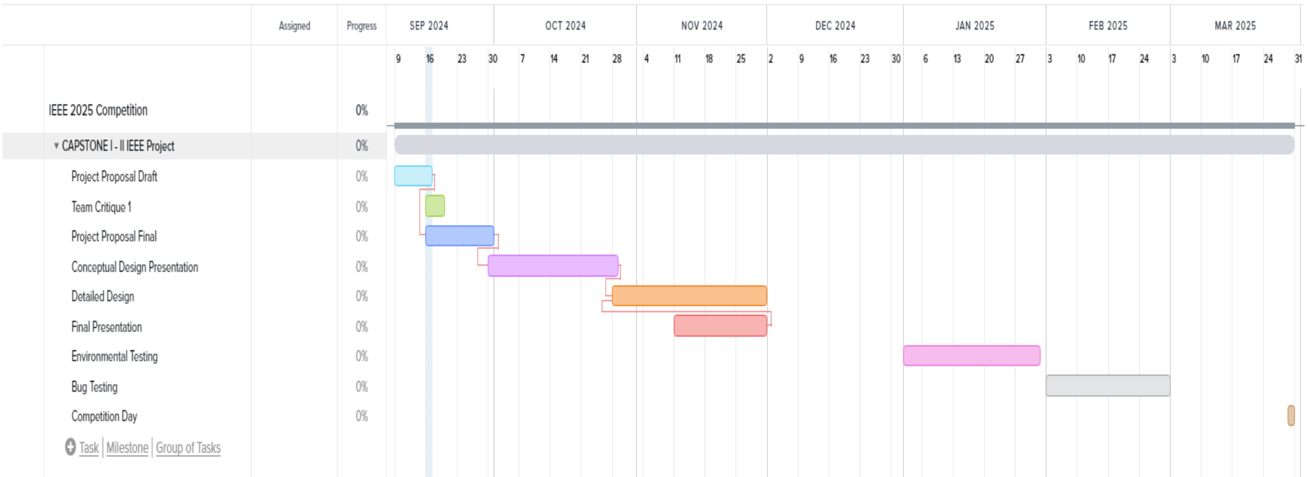
This design ream shall follow not only the rules of the competition Mining Mayhem, but also the National Electrical Code safety procedures, associated National Fire Protection Agency procedures, and abide by priacy laws. The

Resources - Breakdown

- BOM

Item	Cost per Item	Quantity	Total Cost for Item	Link to Item
GROVE ULTRASONIC RANGER V2.0	$4.30	4	$17.20	101020010 Seeed Technology Co., Ltd | Development Boards, Kits, Programmers | DigiKey
Adafruit LSM6DSOX + LIS3MDL breakout board	$19.95	1	$19.95	Adafruit LSM6DSOX + LIS3MDL - Precision 9 DoF IMU [STEMMA QT / Qwiic] : ID 4517 : Adafruit Industries, Unique & fun DIY electronics and kits
Lithium Iron Phosphate Battery	$91.43	1	$91.43	https://www.power-sonic.com/wp-content/uploads/2020/04/PSL-SC-1270-technical-specifications.pdf
Lithium Iron Phosphate Battery Charger	$129.27	1	$129.27	https://www.zeusbatteryproducts.com/wp-content/uploads/downloads/ZEUS_LiFePO_CHARGER_PCCG-LFP14.4V15A_SPEC_SHEET_REVV2.2.pdf
Total				

- Timeline



- Personnel
    - Sean Borchers - Electrical Engineering major with a Mechatronics concentration. Proficient in CAD software (AutoCAD, Inventor, SolidWorks), MATLAB, C++
    - Alex Cruz – Electrical Engineering major. Proficient in Python, and C++. Some familiarity with machine learning.
    - Sam Hunter – Computer Engineering major. Proficient in C++.
    - Dakota Moye – Electrical Engineering major with minors in Physics and Math. Proficient in C++, MATLAB, Arduino IDE. Some experience with Python, Inventor, 3D Printing, PuTTY.
    - Alejandro Moore – Electrical Engineering major. Proficient in C++, C#, C, Assembly, Python, AutoCAD, PLC, and Altium. PCB Design experience and BNC/Ethernet cable installation experience.

Ethics

Works Cited

https://github.com/lchapman42/Control-Sensing-Wireless-Charging-Robot/blob/main/Documentation/Experimental%20Analysis/Experimental%20Analysis.md#specification-14---frame-weight-requirements - is the experimental analysis section where the sensor placement for the ultrasonic sensors can be seen

Control-Sensing-Wireless-Charging-Robot/Documentation/Signoffs/Orientation-Signoff.md at main · lchapman42/Control-Sensing-Wireless-Charging-Robot (github.com) - is the signoff for the orientation sensors

Control-Sensing-Wireless-Charging-Robot/Documentation/Signoffs/ReidCrews-Signoff-Location.md at main · lchapman42/Control-Sensing-Wireless-Charging-Robot (github.com) - is the signoff for the ultrasonic sensor

Imaging Electronics 101: Understanding Camera Sensors for Machine Vision Applications (edmundoptics.com) - is an intro to camera sensors

Machine Vision Camera Selection Guide (mech-mind.com) - talks about picking cameras specs

[source raspberry pi] - https://projects.raspberrypi.org/en/pathways/machine-vision

[source qr-code] - https://jrkwon.com/wordpress/wp-content/uploads/2023/02/AIM-2015-Final.pdf

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[Hough Transform source]W. Wang, A. Tan-Torres, and H. Hamledari, "Lecture #06: Edge Detection." Available: http://vision.stanford.edu/teaching/cs131_fall1718/files/06_notes.pdf

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[Object detection source]"What is Object Detection in Computer Vision?," *GeeksforGeeks*, May 10, 2024. https://www.geeksforgeeks.org/what-is-object-detection-in-computer-vision/