DESCRIPTION AND OPTIMIZATION OF DESIGN

General Structure

The mine detector is made up of a plywood exterior, with two ultrasonic range finders to determine position, a 7-Segment display indicating mine count, a camera with video feed, an electromagnet to pick up the can lids, and a metal detector to find the can lids.

Many techniques have been used to optimize the performance of the mine detector. The mine detector has its weight distributed quite evenly to minimize unfavourable movements such as tipping. The heaviest part, the electromagnet, is the only part at the front of the vehicle along with a load cell. The plywood material of the beam means that the electromagnet will be the heaviest component, but the design of the electromagnet was created to minimize the amount of material used. The other components, including the breadboards, arduino, and sensors have all been placed at the back of the vehicle to balance out the weight of the electromagnet. The enclosed system at the back of the vehicle means that all the electronic parts are protected. The user is also protected when the vehicle is in use, significantly reducing the risk of injury.

The placement of the wheels were selected to stabilize the vehicle. A traditional 4 wheel design was used in order to mimic the weight distribution on cars or trucks. This further increased the stability of the vehicle.

The width of the vehicle was chosen to optimize the planned path. A 20 cm width is small enough to accurately and precisely detect and determine the location of mines, but is also big enough so that the preplanned path is not exceedingly long. It will also be adequately capable of carrying the can lids retrieved. The length and height of the vehicle were chosen so that all the components fit comfortably, but the extraneous space is minimized.

The electromagnet has been optimized to reduce injuries. Traditional electromagnets require a high current in order to produce a significant magnetic field. However, the electromagnet on the mine detector is attached to a grooved beam which is then pulled up 1 by a servo motor. This design eliminates the need for a high current which may lead to injuries. The position of the electromagnet was chosen so that there is minimal interference with the other components. It is placed at the furthest possible point from the Arduino, but is also close enough so that is adequate space for the electromagnet to turn and drop the soup can on the load cell.

Materials

The cart will be made of a plywood, a light but strong material ideal for building a mine detectors. Plywood has enough weight to it that it will not be excessively difficult to balance the device but is also not too heavy that it would make the motors unable to drive the cart. It would be able to handle carrying the many components of the mine detector such as the circuitry, crane, camera, and can lids easily. It is easier to mould relative to plastic or metal, which is vital to be able to customize the mine detector to conform to the requirements.

Crane

The crane is mounted to the front of the cart, and is made with plywood. It is designed to be rigid and strong, enough to support the weight of the electromagnet, metal detector and can lid, but not cumbersome and heavy. The crane has a height of 23 cm, just enough for its end to touch the ground. The height ensures that the electromagnet installed at the end of the crane will be within range to attract the can lid. The crane is made of two sections: a horizontal and vertical section.

The horizontal section is connected to the front body of the cart at a servo motor, which will allow the crane to rotate 180 degrees. It is 15 cm in length, allowing the crane to sweep the area in front of the cart, ensuring that the wheels will not obstruct the path of the can lid when attempting to pick it up. The servo was selected as it granted adequate precision in controlling position at an affordable cost. The crane is designed such that after rotating 180 degrees, it will hover over the load cell on the cart and dispense the can lid. It then rotates back to its original position at the front of the cart and remains in that position until it picks up another can lid. Due to limitations of the servo, the crane will only be able to rotate 180 degrees in one direction. This limitation is taken into consideration when programming the route of the cart, so the crane will only rotate in the direction away from the wall.

The vertical section is connected to the tip of the horizontal section. It is 23 cm long, reaching to the ground. A continuous servo motor is installed at the tip of the horizontal section. The shaft of the motor extends through a slit on the vertical section. A gear is located on the end of the shaft, securing the two sections. A gear rack is glued onto the side of the vertical section, in contact with the gear at the end of the motor shaft. The gears and gear racks are plastic and were selected for price and quality. As the gears in the purchased set are uncomfortably thin, several gears of the same size will be glued together in superposition for reinforcement. The same will be done to the gear racks.

When the continuous servo motor is activated, the gear spins along the gear shaft, which raises the entire vertical section of the crane. Given the projected dimensions and weight of the electromagnet and lid, the motor was selected to generate enough torque to lift the vertical section reliably. The continuous servo will remained activated to lock the vertical section of the crane in the lifted position. When the electromagnet and lid are lifted, the horizontal section is rotated and the can lid is dispensed. The dimensions are optimised such that the crane, in lifted position, will be higher than the wheels and front body of the cart. To return to the initial position, the continuous servo motor is turned off, and the vertical section will slide to its lowered position due to gravity.

Electromagnet

The electromagnet will be homemade with iron nails and insulated copper wire. Iron is an ideal ferromagnetic material as it generates an increased magnetic field and is both convenient and affordable. The longer and wider the nail, the stronger the magnetic field generated. The coil is wrapped around the nail as tightly as possible to maximise the magnetic field generated, as the strength of the magnetic field is directly proportional to the number of coils. The ends of the wire are exposed by stripping the insulation to improve connection. The circuit is simply connected to the power and ground pins on the microcontroller, which provides a potential of 5V. This is easily able to power an electromagnetic strong enough to pick up can lids. As it is connected to the microcontroller, the electromagnet can easily be activated and deactivated. The direction of current and strength of the field cannot be manipulated by the Arduino, but such capabilities are unnecessary. As such, the simplicity of the electromagnet is optimal for the task it is expected to perform, which is merely to pick up, then drop then can lid.

The electromagnet will consist of several identical nails, wired in parallel. The heads of the nails will point toward the ground and contact the can lid directly. The nails will be arranged symmetrically in a circular pattern, secured by a metal plate on the end of the vertical section of the crane. This optimises the area of the magnetic field generated as a whole, which means that the can lid is not required to be perfectly centred to be picked up by the electromagnet. In addition, when lifting the can lid, the force is distributed more evenly across the surface of the lid, which secures the lid more safely when compared to the use of a single, large electromagnet.

The majority of the time, the electromagnet will remain deactivated to prevent interference with the metal detector. It is only activated by the microcontroller when a can lid is detected. After the can lid is captured and dispensed, the electromagnet is again deactivated.

Movement

The movement of the cart will be controlled in a two-wheel drive fashion. Two wheels driven by two separate motors will be placed at the front of the cart, facilitating direction as the cart sweeps the designated area. They will also provide the power to drive the cart, leaving the back wheel to simply rotate as necessary for movement. The motors will be programmed to run at identical speeds to move forward and differential speeds to change direction. For example, to turn left, the right motor will run faster than the left motor to turn the cart, as during a left turn the left wheel will have a smaller turning radius and therefore travel a shorter distance.

This is significantly better than a single axle connecting the two wheels and will ensure smooth turns and maintain the balance of the cart. A four wheeled drive would be more complex to program. It would require differential control of all four motors, which is complex to computerize and develop mechanically. Mechanically, all four motors would have to be checked that they are all running at the same torque level and this would require significant power from the Arduino. This would detract from the power distributed to the other components of the cart, such as the ultrasonic sensors and electromagnet. Using this method could potentially lead to many programming and mechanical issues. The marginal increase in performance of the end result does not justify the purchase of two more servo motors. It was also decided that a differential gear would not be built as they are quite complex devices and it is better to focus on the metal detection and retrieval rather than the basic movement of the cart.

It is also important to maintain appropriate balance of the cart. The center of mass of the cart should be maintained closer to the front wheels and stay relatively low to the ground. This prevents the issue of the front wheels losing contact with the ground in case the torque from the motors exceeds the force of gravity, which could flip the cart if due care is not taken.

Continuous rotation servo motors were selected for this project for several reasons. These servo motors have no limit on its range of motion, which is helpful for driving the wheels of the mine detector. They are controlled with Pulse Width Modulation (PWM) signals, which indicate the speed and direction of rotation. They are simpler than DC motors, as they have built in controllers, eliminating the need to build an extensive circuit or the use of a motor shield as an intermediate medium between the motors and Arduino. They only need a power supply and pulse signal, which is supplied by the Arduino. This would save much time and troubleshooting, keeping the movement circuits as simple as possible.

Metal detection

The metal detector serves to detect the presence of a can lid. It consists of a circular coil with a radius of 5 cm. The search coil is crafted with around 4 metres of stranded wire, wrapped around a cardboard cylinder. The width of the cylinder is 5 cm. Two holes in the cylinder allow the ends of the wires to travel through and be secured in place. The holes are located in the middle of the cylinder, 2.5 cm from either edge. The circuit consists of a 1kΩ resistor, a 10μF capacitor and a relay diode. Two pins on the Arduino are used for metal detection. One provides pulses, while an analog pin reads the potential over the capacitor.

The effective range of the metal detector is the same as the radius of the coil. Thus, the detector can detect can lids up to 5 cm away. The microcontroller will read the voltage values per pulse. The detector is calibrated by the software. As it is mounted close to the iron nails from the electromagnet, it is calibrated to include the increased inductance due to the iron nails in the reference readings. Thus, only the metal can lids will effect a change in inductance, upon which the microcontroller will activate the electromagnet, picking up the lid. The software will so written such that the cart will continue driving for a few seconds after a lid is detected, stopping when the maximum change in inductance is reached. This ensures that the lid will be at its closest point to the detector, fully within range of the electromagnet.

The metal detector is mounted to the end of the crane, around the circular plate of the electromagnet. It is optimised such that any passing lids will immediately be detected, but the moving parts of the main body of the cart will have no effect on its inductance. In addition, the range is designed such that the lids will only be detected when they are reasonably close enough to be attracted to the electromagnet.

Wall Detection

The mine detector must be able to determine its location relative to the walls of the search area to avoid collisions or getting stuck. Two ultrasonic range sensors will be used for this. These sensors send an ultrasonic pulse that is read back with the echo pin on the sensors to determine the distance from a barrier. Through emission and reception of such a signal, the distance to an obstacle can be measured by calculating the time elapsed. One such sensor will be on the front of the mine detector and another will be on the side to account for corners. The ultrasonic sensors will be wired into a simple circuit consisting of an LED to indicate that the circuit is functional and estimate the distance to a wall and a current limiting resistor. The apparatus will be ultimately controlled by the Arduino microcontroller.

Ultrasonic sensors were chosen for their accuracy (up to 3 mm) and the range that they could detect obstacles (up to 400 cm). They are also relatively compact compared to optical sensors and they are unaffected by dust or dirt that might cloud a lens. Although this project deals only with walls as obstacles, the sensors can also detect complex objects such as wire or mesh as well as transparent objects such as plastic or glass. Ultrasonic sensors are optimal because only do they allow detection of obstacles, they can also determine their location relative to a wall which could allow for determining positional information about the mine detector within the search area.

Load Sensor

The weight sensor will detect increases in mass with a load cell and indicate if a can lid has been placed in the back of the cart. This will facilitate counting the number of lids that have been retrieved by the mine detector. The can lids will be transferred from the crane to the back of the cart, where they will be placed on top of the load cell. The weight sensor consists of two components: the straight bar load cell (strain gauge) and the load cell amplifier. The strain gauge is wired to the load cell amplifier, which is wired to the Arduino microcontroller.

The bar load cell contains four strain gauges, of which two will measure tension and two will measure compression, set up in a wheatstone bridge formation to measure small changes in resistance in response to a force applied to the load cell. However, these changes in resistance are typically very small, which is where the load cell amplifier comes in. If an extremely sensitive device that could detect these small changes in resistance was used, the cost of this mine detector would skyrocket. By using an amplifier, a small change in resistance will indicate the change in voltage that translates into quantifiable data about the force applied to the load cell. This is an affordable and accurate option to detect whenever a can lid has been placed in the back of our cart.

Camera

The OV0706 Camera was selected for its compactness and qualities compatible with this project. It is an active-pixel digital image sensor. The camera is capable of 30fps video output with a working voltage range compatible with the Arduino at 4.8-6.5V DC. Its lower power consumption is optimal for safety and preservation of the circuitry. Its settings, such as frame size, exposure, and gain, can be modified to the desired level. It compiles pictures into JPEG files which are ideal for transmitting. The VGA resolution of the pictures also reduces the amount of data that will be transmitted through the Bluetooth connection. In the programming of the OV0706 module, a library provided by Adafruit (github.com/adafruit/Adafruit-VC0706-Serial-Camera-Library) will be used.

The bluetooth shield selected is capable of a master/slave bluetooth connection. It is by default programmed to be the slave in the pairing This design makes it much more convenient to have a single interface as well as more cost effective. With a transparent transmission, a microcontroller such as the Arduino is not necessary.

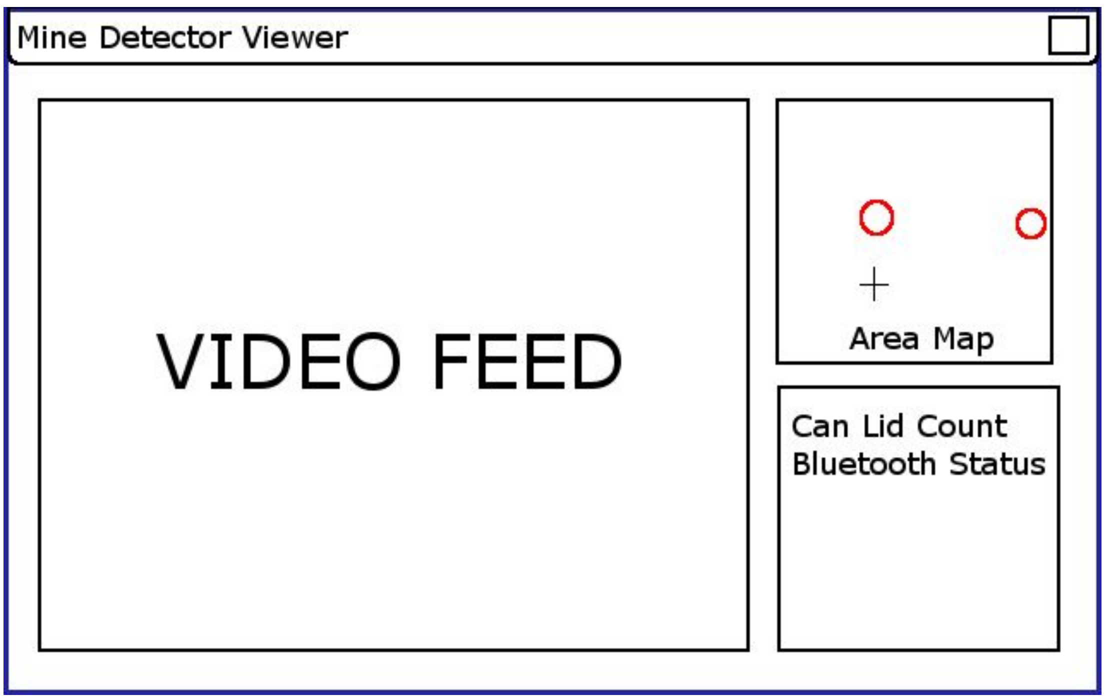
Mine Count

A Seven Segment Display will be used on the unit to display the number of mines collected. The display is 1 inch tall with low current operation but bright display, making it optimal in terms of space saving and power conservation. Like the other components of the mine detector, it has its own independent circuit and can be mounted easily on the mine detector. This allows for independent troubleshooting and ease of construction.

Video Transfer

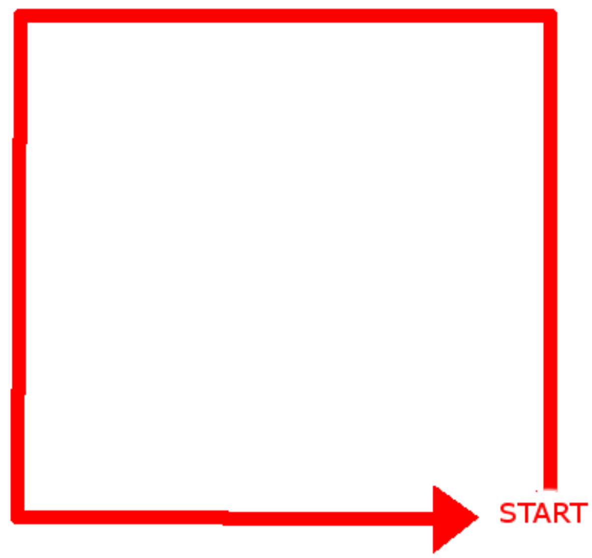
The Arduino Mega 2560 Rev 3 has limited memory and processing power (hence its categorization as a microcontroller) and so, cannot facilitate the transfer of video over a wireless connection. However, the Arduino, using its accessories, will capture low resolution photos and send them individually to the receiver. The receiver will then continuously display the transferred photos to simulate the effect of a video. Camera will take 5 photos a second as to not strain the processing powers and memory of the Arduino.

Two main components are used by the Arduino in the video capture and transfer system: a OV0706 Camera Module and a Bluetooth Module HM-10 and shield.

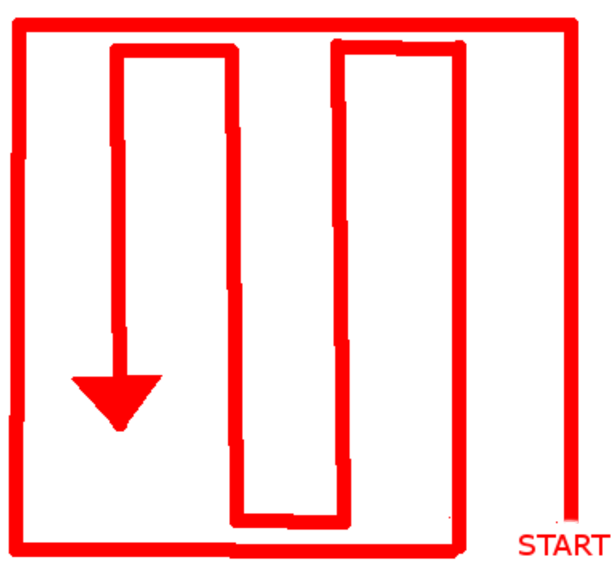


The user interface for viewing the status of the mine detector will feature the required video feed, a map of the area, and indications as to the bluetooth pairing between the PC and the mine detector. The area map will plot both the position of the mine detector (based on data from the ultrasonic sensors) and positions at which the can lids were picked up.

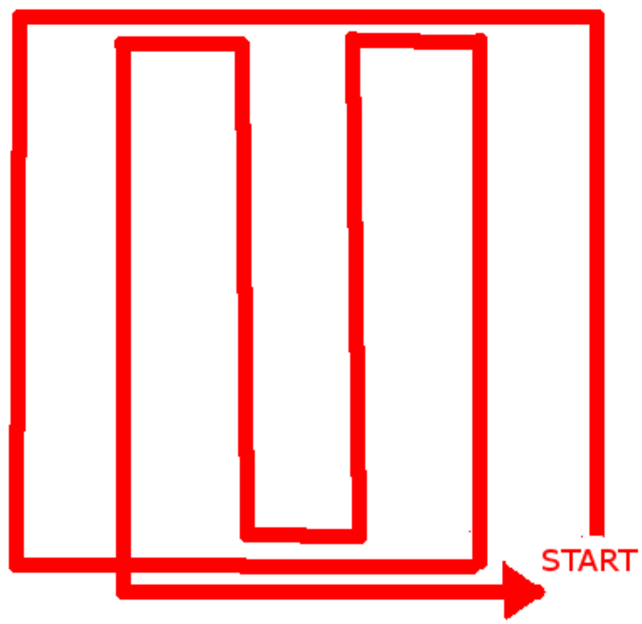
Programmed Path of Mine Detector



The mine detector will initially complete a loop around the 3 m by 3 m area. This is so that any can lids at corners and against the walls will not be missed. From the diagram, it is clear that if the mine detector keep count of how many turns it has made, it knows that it is still completing its initial lap if the counter is under 4. Due to constraints from the servo (it can only turn 180° in one direction), this path is ideal.



The mine detector will then systematically sweep the entire area. The width of each path that the mine detector travels will be the diameter of the circular disc hanging on the crane (0.1 m). This is to account for the possibility that can lids may be between the pre-programmed rows of the mine detectors path of travel. From the diagram, it is clear that the mine detector knows to turn left if it is on an odd-numbered turn. As well, if the mine detector knows to turn right if it is on an even-numbered turn.



When the mine cart completes the area sweep, it will return to its starting position. Since the path is pre-programmed, the arduino will know at which turn it has completed the area sweep.

Path Calibration Using Position

As the operation of the mine detector progresses, the mine detector will stray from the ideal path due to inaccuracies in the motor and due to its load. For this reason, path calibration is needed after each turn is completed so that it matches the desired path. After each turn, the distance from the Arduino to a parallel will be noted (using the ultrasonic sensor on the side of the detector). Based on the direction of deviation, the detector will either be turned slightly to the left or slightly to the right. After the adjustment is made, another distance reading will be taken. If there is still an unacceptable amount of deviation, the detector will make another adjusting motion. When the alignment is satisfactory, the detector will continue on its path. An acceptable deviation is ± 10%. However this uncertainty may be altered based on what testing of the motors yield.

Production Schedule

Date	Task
December 10	Finish testing the Bluetooth module with ultrasonic sensors to ensure it can pair with a computer and that it can transfer data from the arduino to the computer.
	Finish building the disk that hangs at the end of the crane. This disk consists of metal nails and the coil for the metal detector.
	Finish testing the the electromagnet and the metal detector to ensure that they are able to fulfill their functions.
December 16	Finish building the crane. This includes assembling the gears with the continuous servo motor and assembling the disk with the rack gear. Make sure that it is structurally stable.
	Finish testing the two wheel drive (with two accessory wheels) to ensure that the mine detector is able to drive forward, drive backward, stop, and make 90° turns.
	Finish testing the camera module to ensure that it can produce satisfactory pictures.
December 17	Finish programming the Arduino for its interactions between the ultrasonic sensors, metal detector, and motors.
	Finish constructing the 3m by 3m area walls.
	Finish testing the load cell so that the Arduino takes note of when the load on the cell increases.
	Finish connecting the motors and the ultrasonic sensors.
	Finish testing the the camera-Bluetooth system to ensure that a picture can be transferred from the Arduino to a PC.
December 20	Finish testing the Arduino to ensure that it takes the desired path around the 3m by 3m area using ultrasonic sensors.
December 23	Finish testing the the gear mechanisms in the crane (which includes the servo at the top of the crane) to ensure that the gears do not slip and that the crane works as intended.

Date	Task
December 23	Finish programming the computer software to view the status of the mine detector.
	Finish testing the digit display so that it displays whichever digit is desired.
December 27	Finish connecting the crane and drive systems.
December 28	Purchase and cut plywood container.
December 29	Finish testing the interactions between the crane and drive systems to ensure that the detector stops when a lid is detected.
December 30	Finish connecting the crane, drive, and load systems.
January 2	Finish connecting the crane, drive, load, camera, and Bluetooth systems. This should be the finished product.
January 7	Finish testing the finished product. The camera feed should be operational and the PC program should be display the position of the detector and can lids.
January 8 - 11	Buffer time during which to solve and outstanding bugs in the product.
January 12	Project Due Day

NOTE: The drive system includes the motors and the ultrasonic sensor

To track the progress of construction and the construction team's adherence to the production timeline, a shared excel spreadsheet will be used to note tasks completed. It is the responsibility of the construction team to update the spreadsheet daily. As well, video recordings will be used to document the completion of anything task noted in the timeline.

Bill of Materials

Item	Quantity	Price	Total
BC338 Transistor	1	$0.10	$0.10
10µF Capacitor	3	$0.10	$0.30
2.2kΩ Resistor	2	$0.10	$0.20
39kΩ Resistor	1	$0.10	$0.10
10kΩ Resistor	1	$0.10	$0.10
470Ω Resistor	1	$0.10	$0.10
1kΩ Resistor	15	$0.10	$1.50
Breadboard Wires	1	$9.65	$9.65
Load Cell (TAL220)	1	$5.56	$5.56
Load Cell Amplifier - HX711	1	$6.75	$6.75
7-Segment Display	1	$4.29	$4.29
Arduino Mega 2560 Microcontroller Rev3	1	$38.50	$38.50
HS-422 Servo Motors - Continuous	4	$8.95	$35.80
HC-SR04 Ultrasonic Range Sensor	2	$5.09	$10.18
OV0706	1	$35.68	$35.68
AA Batteries	10	$0.20	$2.00
Plywood Outer	1	$5.20	$5.20
Bluetooth Shield	1	$18.00	$18.00
		Total	$174.01

Sources

Instructables (2017, September 23). OV7670 Arduino Camera Sensor Module Framecapture Tutorial. Retrieved December 03, 2017, from http://www.instructables.com/id/OV7670-Arduino-Camera-Sensor-Module-Framecapture-T/

Electronics Stack Exchange. (2012, April). Controlling an electromagnet with Arduino. Retrieved December 03, 2017, from https://electronics.stackexchange.com/questions/30918/controlling-an-electromagnet-with-arduino

DC Motors. (n.d.). Retrieved December 03, 2017, from http://www.electronics-tutorials.ws/io/io_7.html

How many sensors can be supported by a single Arduino unit? (2016, August). Retrieved December 03, 2017, from https://arduino.stackexchange.com/questions/28764/how-many-sensors-can-be-supported-by-a-single-arduino-unit

How to Connect Load Cell to Arduino. (2017, December 02). Retrieved December 03, 2017, from http://www.theorycircuit.com/how-to-connect-load-cell-to-arduino/

Instructables (2017, September 26). How to Connect Load Cell to Arduino? Retrieved December 03, 2017, from http://www.instructables.com/id/How-to-Connect-Load-Cell-to-Arduino/

Instructables (2017, October 18). How to Control an Electromagnet With an Arduino. Retrieved December 03, 2017, from http://www.instructables.com/id/How-to-Control-an-Electromagnet-with-an-Arduino/

How to Determine Voltage Required. (2012, June 26). Retrieved December 03, 2017, from http://forum.arduino.cc/index.php?topic=111679.0

Introduction to the Arduino Board. (n.d.). Retrieved December 03, 2017, from https://www.arduino.cc/en/Reference/Board

Kale, E. (2016, October 03). Build Your Own Metal Detector with an Arduino. Retrieved December 03, 2017, from https://www.allaboutcircuits.com/projects/metal-detector-with-arduino/

Mitov, B. (2017, April 28). Arduino and Visuino: Measure Weight with HX711 and Load Cell. Retrieved December 03, 2017, from https://www.hackster.io/mitov/arduino-and-visuino-measure-weight-with-hx711-and-load-cell-76de80

Schwartz, M. (2013, October 01). Wireless Camera with Arduino and the CC3000 WiFi chip. Retrieved December 03, 2017, from https://openhomeautomation.net/wireless-camera/

Servo Library. (n.d.). Retrieved December 03, 2017, from https://www.arduino.cc/en/Reference/Servo

Instructables (2017, September 20). Simple Arduino Metal Detector. Retrieved December 03, 2017, from http://www.instructables.com/id/Simple-Arduino-Metal-Detector/

Udanis, A. (2016, January 08). The Best Wire for Breadboarding. Retrieved December 03, 2017, from https://www.allaboutcircuits.com/news/the-best-wire-for-breadboarding/

Instructables (2017, October 22). Ultrasonic Range Detector Using Arduino and the SR04 Ultrasonic Sensor. Retrieved December 03, 2017, from http://www.instructables.com/id/Ultrasonic-Range-detector-using-Arduino-and-the-SR/

What are the 5V and VIN pins for? (2014, October). Retrieved December 03, 2017, from https://arduino.stackexchange.com/questions/4458/what-are-the-5v-and-vin-pins-for

Working with a Load Cell and an Arduino. (2012, April). Retrieved December 03, 2017, from https://edg.uchicago.edu/tutorials/load_cell/