Request for Proposal #1

The Traffic Cone Deployment Machine

Need

A city engineering contractor needs to develop concepts for automatic deployment of traffic cones based on the given instructions.

Goal

Design and manufacture the scaled-down, proof-of-concept prototype of a mobile platform that can travel along a designated lane and deploy traffic cones.

Specifications

The machine is expected to deploy a number of small size traffic cones (referred to as "cones"), unspecified *a priori* but at least 4 and not more than 12, within a designated lane. The lane is $25^{\pm1}$ cm wide and $400^{\pm10}$ cm long, and it is defined by two lines along the length made of black hockey tape and with a width of $2^{\pm0.5}$ cm. Each line can have ±1 cm variance. Each cone is made of plastic and weighs $48^{\pm5}$ g, with $6^{\pm0.5}$ cm and $2^{\pm0.5}$ cm in bottom and top diameters, respectively, and $9^{\pm0.5}$ cm in height. The base of each cone has a square section with $9^{\pm0.5}$ cm in length. Samples are available from the client. The cones are loaded in the machine by the operator prior to the operation. Methods of loading (and unloading) cones into the machine are up to the design, but must be convenient for the operator, e.g., easily accessible. The deployment of the cones during the operation depends on whether the machine detects a "hole" or "crack" on the ground as well as their distance from each other, as specified in the Operation section. Each hole is represented by a square mark on the floor, made of black hockey tape and with a length of $4^{\pm0.5}$ cm, whose centre is on the lane centreline with ±0.5 cm variance. Each crack is represented by a lateral line normal to the lane borderlines with a length of $15^{\pm1}$ cm and width of $2^{\pm0.5}$ cm. A Start Line is specified at the beginning of the designated lane. The machine shall begin the operation from a location so that its front end is behind Start Line, and travel along the lane to deploy the cones at the correct spots, as specified in the Operation section. In each operation, the machine shall perform the deployment task autonomously until it deploys all the cones loaded in the machine and/or reaches the end of the designated lane, and stop where the entire machine is behind Start Line in the standby mode displaying a completion or termination message on an LCD and ready to communicate the operation information per the operator's request through a keypad. The entire operation shall take no longer than 3 minutes. The menus displayed on the LCD should be self-explanatory, and provide easy navigation for operators of various skill levels. The company requires that the machine be portable with no need for installations in the field, and as such there are constraints on weight and dimensions. For safety purposes, the machine must have an easily-accessible emergency STOP switch that stops all the mechanical moving parts immediately. The machine must use an on-board power supply.

Operation

The machine is initially positioned behind Start Line in standby mode. The operation begins by pressing the <*start*> button on a keypad. The machine then travels along the lane until it detects a hole or crack. If the machine detects a hole within the lane, the machine may have to deploy one cone on top of the hole, such that the cone completely covers the hole. If the machine detects a crack, the machine may have to deploy two cones on top of the crack, such that they do not contact each other and each cone covers at least 5 cm of the crack. In either case, the cones must be positioned within the lane. In addition, the deployment of the cones must comply with the following instructions:

– After deploying cone on a hole, if there is an immediate next hole whose distance from the hole is less than 15 cm, then the machine must not deploy any cone over this hole.
– After deploying cone on a hole, if there is an immediate next crack whose distance from the hole is less than 20 cm, then the machine must not deploy any cones over the crack.
– After deploying cones on a crack, if there is an immediate next hole whose distance from the crack is less than 20 cm, then the machine must not deploy any cone over the hole.
– After deploying cones on a crack, if there is an immediate next crack whose distance from the crack is less than 10 cm, then the machine must not deploy any cone over this crack.

Note that the above-mentioned conditions apply only to the immediate next hole or crack after deployment is done on a current hole or crack. The order of holes and cracks is determined from Start Line. All distances are measured between the centerlines (of the cracks) and centre points (of the holes.) The distance between the adjacent holes and cracks is not less than 5 cm. When all the cones in the machine are deployed and/or the machine reaches the end of the designated lane, the machine is expected to stop behind Start Line. The entire deployment process must be done autonomously and must take no longer than 3 minutes. Upon completion of the operation, the machine must display a completion or termination message on the LCD and be ready to communicate the operation information per the operator's request through a keypad, including the operation time, number of cones deployed, and number of holes and cracks within the lane and their distance from Start Line.

Depending on the operation time, quality of deployment actions, and accuracy of the retrieved information, the performance of the machine will be evaluated, as detailed in the following section.

Performance Evaluation

The prototype will run two separate but consecutive operations, and the total time, accuracy and quality of these operations are aggregated for evaluating the overall performance. Reward and Penalty points will be given to the prototype performance according to the following scheme. Each operation is qualified for scoring if, in addition to the lack of other disqualification factors (see Constraints section), the machine deploys at least 3 cones within the lane accurately, detects at least one hole and one crack correctly, stops and displays the completion or termination message at the end of its operation, and is able to communicate the operation information per the operator's request through a keypad.

- Each "qualified" operation + 1000
- Machine "returns to" Start Line + 500
- Each hole "detected correctly" + 200

➢ Each hole "detected falsely"	− 200
➢ Each crack "detected correctly"	+ 200
➢ Each crack "detected falsely"	− 200
➢ Each cone deployed "incorrectly"	− 100
➢ Each cone deployed "accurately"	+ 200
➢ Each cone deployed "inaccurately"	− 200
➢ The total number of cones deployed is correct	+ 200
➢ The total number of holes is correct	+ 200
➢ The total number of cracks is correct	+ 200
➢ Each hole whose location is recorded "correctly"	+ 200
➢ Each hole whose location is recorded "incorrectly"	− 200
➢ Each crack whose location is recorded "correctly"	+ 200
➢ Each crack whose location is recorded "incorrectly"	− 200
➢ The operation time recorded on the display is "correct"	+ 500
➢ The operation time recorded on the display is "incorrect"	− 300
➢ Time penalty	− 10 per second of run (from start)
➢ Each "disqualified" operation	Not scored
Bonus Points for Extra Design Features:	
➢ Robustness and Durability	0 to +500
➢ Operability and Sustainability	0 to +500
➢ Elegance and Safety	0 to +500
➢ Dexterity	0 to +500
➢ Extendibility	+ 500
➢ Compactness and Portability	+ 500
➢ Real-time Date/Time Display	+ 200
➢ Permanent Logs	+ 200
➢ PC Interface	+ 200
➢ Remote Operation	+ 200

Constraints

a. The entire prototype shall completely fit within a 50×50×50 cm^3 envelope at all operation times.
b. The weight of the machine (without the cones) shall not exceed 8 kg.
c. The total prototype costs (cones notwithstanding) shall not exceed $230 CAD before shipment and taxes. For parts purchased in foreign funds, the exchange rate reported by the Central Bank of Canada at the end of business day on January 7th, 2019, will be considered. The manufacturing labour

is not considered on top of the material costs in the prototype, unless a part is manufactured using a 3D-printer, laser cutter or CNC machine. In such cases, an additional cost of $5 CAD per manufacturing hour will be assumed. The G-code and exact manufacturing time for such parts shall be included in the final report.

d. Use of materials such as paper (of any type) or corrugated plastic for fabricating the machine, and non-standard fasteners such as duct tape, masking tape, hot glue, etc., is not acceptable. It is imperative to have the client's explicit consent for other cases similar to the above.

e. The machine must use its own on-board power supply during the operation.

f. The machine must have an easily-accessible emergency STOP switch that stops all the mechanical moving parts immediately.

g. The machine must be fully autonomous, and no interaction with an external PC or remote control is permitted during the operation. The operation must begin by pressing a <*start*> button on the keypad.

h. The operator must be able to set up the machine for the operation and take it away afterward conveniently (to the referee's discretion) with no need for modifying the designated lane at any time. No installation or instrumentation is allowed in addition to what is devised within the machine. No actuation or sensing must occur in the machine prior to the start of the operation.

i. At the end of each operation, the machine display must be on prompt to show the following information per the operator's request through the keypad: the operation time, number of cones deployed, and number of holes and cracks within the lane and their distance from Start Line.

j. The machine user interface for both operation and information retrieval shall be self-explanatory, and provide easy navigation for operators of various skill levels.

k. Each cone is deployed "correctly" if the machine disconnects from the cone, and positions it such that it remains completely inside the lane stand-up. Otherwise, if the machine positions the cone such that it tilts over or parts of the cone are on the border lines or the cone is out of the lane or it remains attached to the machine, the cone is deployed "incorrectly."

l. Each cone is deployed "accurately" for a hole if the cone remains covering the hole completely, and for a crack if the cone remains covering at least 5 cm of the crack. Otherwise, the cone is deployed "inaccurately." Also, if two deployed cones are found in contact with each other at the end of operation, both deployments are considered "inaccurate." The accuracy of the deployment is assessed only if the deployment is correct. Otherwise, the score for the accuracy of deployment will be zero.

m. Each hole or crack is considered "detected correctly" only if the machine clearly signals its detection when in its vicinity (e.g., light, sound, etc.) The signal for detecting a hole and the one for detecting a crack should be distinguishably different. Otherwise, if there is no signal in the vicinity of a hole or crack, or a signal appears when there is no hole or crack in the vicinity, or a wrong signal is triggered for a hole or crack, a "false detection" is assumed.

n. The location of each hole is recorded "correctly" if the displayed distance with reference to Start Line is within ±10 cm of the real distance (to the hole center point;) otherwise, it is "incorrect." The correctness of the recorded distance is evaluated only if the hole is detected "correctly." Otherwise, the score for the recorded location will be zero.

o. The location of each crack is recorded "correctly" if the displayed distance with reference to Start Line is within ±10 cm of the real distance (to the crack centerline;) otherwise, it is "incorrect." The correctness of the recorded distance is evaluated only if the crack is detected "correctly." Otherwise, the score for the recorded location will be zero.

p. The machine is considered to have "returned to" Start Line if, at the end of operation, the entire machine is behind Start Line.

q. The operation time is the duration between when the <*start*> button on the keypad is pressed and when the machine stops and displays a completion or termination message on its LCD. No actuation or sensing must occur in the machine prior to the start of the operation. The operation time shall not exceed 3 minutes. Further, the time required for setting up the machine before the operation begins shall not exceed 2 minutes.

r. The recorded and displayed operation time is considered "correct" if it equals the time measured by the referee ± 2 seconds. Otherwise, it is assumed "incorrect."

s. Each operation is "qualified" for scoring if, in addition to the lack of other disqualification factors (next constraint), the machine deploys at least 3 cones within the lane accurately, detects at least one hole and one crack, stops and displays the completion or termination message at the end of its operation, and is able to communicate the operation information per the operator's request through the keypad:

t. Each operation is "disqualified" if any of the following happens to the machine or team declares the termination. If the first operation is disqualified, the team will have 2 minutes to fix the system and run for the next time, if they wish.
- structurally collapses, falls over, hangs or jams (for more than 3 minutes) with no termination display, or
- terminates the operation before deploying 3 cones within the lane accurately, or
- terminates the operation before detecting one hole and one crack correctly, or
- does not display the termination or completion message on the LCD at the end of operation, or
- is not able to communicate the operation information per the operator's request through the keypad, or
- runs longer than 3 minutes before terminating the operation, or
- takes more than 2 minutes to set up the machine before the operation begins.

u. Each team will have a period of maximum 2 minutes to set up the machine before beginning the operation. If the set up time exceeds 2 minutes, the run is "disqualified."

v. There will be no control on the conditions of the competition environment. Hardwood or Vinyl tile flooring with bright colour can be assumed (SF4102 floor).

w. No railways or tracks are allowed.

x. The machine must pose no hazard to the operator, and shall not be perceived as hazardous (e.g., excessive vibration or noise, electric sparks during the operation are perceived as dangerous.)

Extra Design Features

The following features would enhance the machine performance, and increase the Bonus Points:

- **Robustness and Durability:** Machine is durably constructed, and functions consistently under different indoor and outdoor lighting, environment and terrain conditions with a low failure rate.
- **Operability and Sustainability:** Little time/effort is needed to set up and calibrate the machine in the field, and the machine is modular so that parts can be replaced or repaired easily.
- **Elegance and Safety:** Machine looks elegant, and operates quietly and smoothly with little or no sensible noise or vibration.
- **Dexterity:** Machine can perform extra functions, such as operating in non-straight lanes and/or on uneven terrains, returning to Start Line and resuming the operation afterward, utilizing sound and/or a secondary GLCD (in addition to the primary LCD) for delivering useful information during or after the operation, etc.
- **Extendibility:** Machine can deploy 25 or more cones and cover 600 cm distance, with little or no need for modifications.
- **Compactness and Portability:** The entire prototype weighs no more than 4 kg (i.e., half of the maximum permitted weight,) and fits within a cubic envelope of $0.30\times0.30\times0.30$ m^3 (i.e., ~22% of the volume of maximum allowed envelope.)
- **Real-time Date/Time Display:** Date (day, month and year) and time (second, minute and hour) are displayed on the LCD in standby mode.
- **Permanent Logs:** Machine stores operation logs of at least 4 previous operations in permanent (EEPROM) memory.

- **PC Interface:** The operation information, including operation logs and date/time, can be readily and directly downloaded from the machine to a PC.
- **Remote Operation:** Machine can start and (emergency) stop the operation by a remote controller.

Expected Outcomes

***Design and Construction Process*:** The team must follow a logical and systematic process in accomplishing their tasks of design, analysis, and fabrication. Conceptual design and system analysis are important steps of this project where the team has to compromise speed, accuracy, reliability, robustness, ease of use, and cost. The detailed process must be reflected in the final report submitted by the team.

***Proposal*:** Each team must work together to generate a proposal documentation on the design. The design proposal should reflect the conceptual design phase, team and project management with the scheduling, the steps to be taken for the detailed design and prototype fabrication, and the methods of manufacturing, integration and debugging to be followed in building the prototype.

***Final Report*:** The final report details the entire process of detailed design, analysis, fabrication, and evaluation.

***Final Prototype*:** The final prototype developed by the team should reflect the work presented in the proposal. Any major or significant change in the design of the prototype after submitting the proposal must be formally agreed upon by the client (instructor) and justified in the final report. The quality of the prototype may vary widely depending on the background of the team, the difficulty of the concept, and other limitations. Many of the deficiencies of these prototypes can be resolved later in the students' academic career.

***Team Dynamics*:** The team must propose in the proposal a solution and the plan for its implementation, and remain *loyal* to the proposal during the entire process. Hence, a close interaction between members of the team is required initially to be able to "*plan ahead.*" Early team dynamics may be strained, but interaction increases as the construction and integration of the machine proceed. Maximum team interaction occurs during the system integration, test and demonstration. The instructor will enhance the team dynamics by spending some time with the teams examining the process. In many cases students remember this team experience (including their teammates) when they are seniors, or even when they are returning alumni. Professional and humane characters are expected in all team activities.

Grade evaluation will be heavily weighted to the generated design concepts, proposal, final report, and the way each individual/team has interacted and performed the tasks. Nevertheless, the final product and performance evaluation (demonstration and competition) will maintain their crucial roles in the overall grade.

Statement of Work

Each team is composed of three students. Conceptual design, system analysis, project planning, and system integration and debugging must be performed through a close interaction of all members of the team. However, for the sake of implementation, tasks can be broken into the following categories:

Processing and Control (Microcontroller)
One student shall be primarily in charge of developing all the software for the system. In addition to combinational and sequential logic required for the algorithms, keypad and display interface with the microcontroller is also part of this assignment. Some extra coding may also be needed for system debugging. Further utilization of the microcontroller may be needed if the team plans to accomplish some of the Extra Design Features, such as Real-time Date/Time Display, Permanent Logs, and PC Interface. For a low-power, high-end microcontroller, the assembly language is the most efficient option for

programming. Nevertheless, some cross-assemblers can translate specific C and/or Basic instructions into machine codes resulting in more convenient programming options, albeit likely creating less tractable codes. For the processing hardware, the use of the microcontroller development board in the Project Kit is permitted if budget allows. Otherwise, the microcontroller student has the responsibility of assembling the microcontroller board, e.g., the Simple Configuration Board. It is required that the microcontroller be functional for basic design features and programmable by the Reading Week, so that system integration and testing may begin right after the Reading Week. Often integration requires additional adjustments to the microcontroller hardware and software.

Mechanism and Actuation (Electromechanical)

One student shall be primarily responsible for constructing the platform, structure and frames and incorporating whatever actuators and mechanisms are required in the system. Major components of the Electromechanical subsystem can include: mobile platform, structure and frames, cone deployment mechanisms, and mounting sensors, microcontroller and keypad/LCD. Some off-the-shelf mechanisms or platforms can be used for the above-mentioned components, but this must be clearly addressed in the proposal and authorized by the instructor. In addition to design and analysis of these components, their fabrication and/or assemblage as well as assigning the locations of the sensors and boards are also parts of the Electromechanical subsystem. Although integration of the entire system might seem as a "mechanical" task by nature, all members of the team should equally and effectively take part in the integration process.

Instrumentation and Interfacing (Circuit)

One student shall construct all the digital and analog interfacing electronics to connect the sensors and actuators to the microcontroller board. This includes motor/solenoid driver circuits. All sensors and input/output signal calibration/protection are also part of this subsystem. In those situations where the primary calibration for a transducer is positional in nature, such as a stop switch, the task is still part of Circuit subsystem, but consultation with the Electromechanical member is advised. For the actuator drivers, the use of the driver board in the Project Kit or driver IC's is permitted if the budget allows, but the Circuit member must design and build at least one "open" circuit (i.e., made of basic components, such as transistors, resistors, capacitors, diodes, timer chips, etc.) for a motor (DC, stepper or servo) in the final prototype and prove its functionality. Shaft encoding and hole and crack detection would be the major sensory tasks of this subsystem, in addition to the driver circuits and cabling. The circuit member shall also complete wiring the machine and acquire suitable power supplies for the actuators, circuits, sensors, and the microcontroller.

Discussion

In this design, speed, accuracy, reliability and budget are competing factors. Designers should first analyze the performance criteria to specify the level of acceptable compromise in each of the above-mentioned factors. A variety of solutions can be proposed for the mobile platform, as well as hole and crack detection and cone deployment mechanisms. Power consumption is an important factor in almost every design. A careful analysis of the force and mechanical power required for the operation is important, in order to reduce not only the electric power but also weight and dimensions.

Students might encounter problems with construction of the product. With limited experience in shop practices, final prototypes may not always work as anticipated. This can be frustrating to the students. As with any life experience, the product building will improve as the students gain maturity, not only in shop practice, but also in engineering science foundations. The final demonstration session provides proof of the paper design. It also demonstrates to students that in real life the result does not always follow the prediction of theory. This is a good time to remind the students that ***"equations, tables and curves are only a mortal's representation of reality."***