Request for Proposal #3

The Ball Dispensing Machine

Need

An engineering R&D company needs to develop concepts for automatic mobile dispensing machines.

Goal

Design and manufacture the scaled-down, proof-of-concept prototype of a mobile platform that can travel along a row of canisters and dispense balls in them based on the given instructions.

Specifications

The machine is expected to dispense balls in a number of canisters, unspecified *a priori* but at least 4 and not more than 10, which are placed on a flat ground in a row with no extra attachments. In each canister, there may already exist one ball, and the machine is required to deploy one ball to empty canisters if they meet the conditions specified in the Operation section. Each canister can be considered as a truncated square pyramid container, with $10^{\pm 0.5}$ cm in height, and base and top sides of $13^{\pm 0.5}$ cm and $11^{\pm 0.5}$ cm length, respectively. The base side is open. Each canister is made of cloth, and coloured in dark-brown both inside and outside. Each empty canister weighs $104^{\pm 10}$ g. Samples are available from the client. The canisters are positioned in a line with ±5 cm variance. Each canister is placed on the ground so that its open side is facing toward either left or right direction normal to the row of canisters (with ±5° variation), when viewed from Start Line toward the end of the row. A Start Line is specified normal to the row of canisters and not closer than 25 cm but not farther than 35 cm from the centreline of the first canister. The minimum distance between the centrelines of two adjacent canisters is 20 cm. The centerline of a canister is defined as a line normally passing through the centre of the side that is facing up. The balls, made of soft rubber in yellow colour, are $6.1^{\pm 0.2}$ cm in diameter, and weigh $18^{\pm 4}$ g. A maximum of 10 balls are loaded in the machine by the operator prior to the operation. Methods of loading (and unloading) balls into the machine are up to the design, but must be convenient for the operator, e.g., easily accessible. The machine shall begin the operation from a location so that its front end is behind Start Line, and travel along the row of canisters to detect them and dispense balls in them, as specified in the Operation section. In each operation, the machine shall perform the dispensing task autonomously until it dispenses all the balls loaded in the machine and/or reaches the last canister or the end of the dispensing range that is not farther than 400 cm from Start Line, 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 a standby mode. The operation begins by pressing the <*start*> button on a keypad. The machine then travels along the row of canisters. After detecting each canister, its open side and whether or not it is empty, the machine dispenses one ball if the canister is detected empty, and moves to the next canister. However, if after servicing a canister there is an immediate next canister whose distance from the canister is less than 30 cm, then the machine shall not dispense a ball in this canister even if it is empty. The distance between the canisters is measured between their centerlines.

The order of canisters is determined from Start Line. When all the balls in the machine are dispensed and/or the machine reaches the last canister or the end of the dispensing range, the machine is expected to stop behind Start Line. The entire dispensing 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, canisters that received a ball from the machine, empty and full canisters after operation, total number of supplied balls, and number of canisters and distance between their centerline and Start Line.

Depending on the operation time, quality of dispensing 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 detects at least 3 canisters correctly, supplies at least 2 balls in 2 different canisters accurately, does not significantly move, shake, mark, scratch the canisters, 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 canister “detected correctly” + 200
- Each canister “detected falsely” − 200
- Each ball dispensed “incorrectly” − 100
- Each “accurate” dispensing action per canister + 500
- Each “inaccurate” dispensing action per canister − 300
- Each correctly reported canister that received a ball from machine + 200
- Each unreported or incorrectly reported canister that received a ball from machine − 200
- Each correctly reported status of canister after operation + 200
- Each unreported or incorrectly reported status of canister after operation − 200

➢ The total number of supplied balls reported is correct	+ 200
➢ The total number of canisters recorded is correct	+ 200
➢ The total number of canisters recorded is incorrect	− 200
➢ Each canister whose location is recorded "correctly"	+ 200
➢ Each canister 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 balls) shall not exceed 8 kg.

c. The total prototype costs (balls 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. Parts of the machine can be in contact with the canisters, but cannot significantly move, shake, mark, or scratch them at any time (to the referee's discretion).

j. 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, canisters that received a ball from the machine, empty and full canisters after operation, total number of supplied balls, and number of canisters and distance between their centerline and Start Line.

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

l. Each canister is considered "detected correctly" only if the machine clearly signals its detection when in its vicinity (e.g., light, sound, etc.) Otherwise, if there is no signal in the vicinity of a canister, or a signal appears when there is no canister in the vicinity, a "false detection" is assumed.

m. Ball dispensing for each canister is considered "correct," if the machine disconnects from the ball, and positions it completely inside the canister. Otherwise, if the machine dispenses the ball such that all or part of it is out of the canister or it remains attached to the machine, the ball is dispensed "incorrectly."

n. Ball dispensing for each canister is considered "accurate," if a correct number of ball (one or zero) is dispensed according to the conditions mentioned in the Operation section. Otherwise, it is "inaccurate." The accuracy of dispensing is assessed only if the ball dispensing is correct. Otherwise, the score for the accuracy of dispensing will be zero.

o. The location of each canister is recorded "correctly" if the displayed distance with reference to Start Line is within ±10 cm of the real distance (to the canister centerline). Otherwise, it is "incorrect." The correctness of the recorded distance is evaluated only if the canister 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 (see Constraints section,) the machine detects at least 3 canisters correctly, supplies at least 2 balls in 2 different canisters accurately, does not significantly move, shake, mark, scratch the canisters, 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 detecting 3 canisters correctly, or
- terminates the operation before supplying at least 2 balls in 2 different canisters accurately, or
- significantly moves, shakes, marks, scratches any of the canisters (to the referee's discretion), 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 lines 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 carry a maximum of 20 balls and supply them to up to 20 canisters, 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, ball dispensing 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 canister and ball 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 canister and ball detection and ball dispensing 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 ***"what we have to learn to do, we learn by doing."***

