Request for Proposal #3

The Lab Packing Machine

Need

A biology laboratory needs to autonomously package daily dietary food for its laboratory rats.

Goal

Design and fabricate the proof-of-concept prototype of a machine that can package various food pieces in a small multiple-drawer parts cabinet based on the given instructions.

Specifications

The machine is expected to package one cabinet in no longer than 3 minutes. The cabinet is a rectangular prism, made of hard plastic in black colour, with dimensions of $220^{\pm5}$ mm in width, $160^{\pm5}$ mm in height, and $70^{\pm5}$ mm in depth. It is divided into 16 equally-spaced compartments; each containing a drawer made of transparent plastic with dimensions of 50^{-5} mm in width, 35^{-5} mm in height, and $65^{\pm5}$ mm in depth. Each drawer is positioned in its compartment with no attachment mechanism, and has a horizontal handle that can be used to open the drawer from its compartment. The top left drawer is considered as Drawer 1 (D1), and other drawers are named row-wise sequentially, e.g., D2, D3, etc. (Drawers 5, 9 and 13 are right below D1, D5 and D9, respectively.) Some of the drawers (minimum 1 and maximum 4) may have a marker on their front face in the centre of the area on top of the drawer handle. The marker is a horizontal line with a length of $35^{\pm1}$ mm and thickness of $10^{\pm1}$ mm, in white colour (electric tape). The marked drawers are not known *a priori*, and must remain empty regardless of the given instructions for the operation. The weight of the cabinet with empty drawers is $473^{\pm5}$ g, and the weight of each empty drawer is $12^{\pm1}$ g. The food pieces are divided into three groups: **a)** Round piece (R), represented by spherical glass marbles with a diameter of $16^{\pm1}$ mm and weight of $5^{\pm1}$ g; **b)** Flat piece (F), represented by flat glass marbles with a maximum width of $19^{\pm1}$ mm, maximum thickness of $8.5^{\pm0.5}$ mm, and weight of $4^{\pm1}$ g; and **c)** Long piece (L), represented by truncated ellipsoids with a major axis of $22^{\pm1}$ mm, maximum thickness of $8^{\pm0.5}$ mm and weight of 0.4 g. The objects may come in different colours, and some irregularities may appear on them. Samples of the cabinet and objects are available from the client for close examinations.

Before the operation, the pieces are to be supplied into the machine separately by the operator in no particular format. A maximum number of 45 of each piece may be supplied to the machine, but the exact numbers are not known *a priori*. The operator also places the cabinet in the machine with all the drawers closed. Methods of loading/unloading pieces and the cabinet are up to the design, but must be convenient for the operator, e.g., easily accessible and no need for disassembling any parts.

For the operation, a combination of three types of pieces in different numbers is to be dispensed in each drawer, based on the operator's inputs through a keypad in the beginning; all drawers are to be closed completely; and the cabinet must be made available for pickup. The operator's inputs consist of a number of parameters related to the daily experiment plan, including **i)** rat (drawer) label to be fed with the dietary food, **ii)** diet type, and **iii)** number of each piece per diet type. Each parameter may be selected from several options, as listed below:

- Rat (drawer) label: any number between 1 and 16, a maximum of 8 rats (drawers) are selected for daily experiments.
- Diet type: R, F, L, RF, RL, FL, RRF, RRL, RFF, RLL, RFL, FFL, FLL, RRFL, RFFL, RFLL, RLLL, FLLL.
- Number of each piece per diet type: 1, 2, 3.

The machine is expected to accept through the keypad only those inputs that are consistent with the above-mentioned list and also comply with the following rules:

- The maximum number of each piece to be dispensed in each drawer is: 2 for R, 2 for F, and 3 for L.
- The maximum number of total pieces to be dispensed in each drawer is 4.

In case of a wrong or inconsistent input, the machine must not accept it, and must wait for a proper input. Furthermore, no piece shall be dispensed in the marked drawers regardless of the initial instructions.

After dispensing the pieces in the drawers, the cabinet must be placed in a designated pickup position in the machine with all the drawers closed. After each operation, the machine is expected to return to the standby mode, display a completion or termination message on the LCD, and be ready to communicate with the operator the operation information. Also, all the remaining pieces must be returned in 3 separate reservoirs, one for each group, after each operation, so that the operator can retrieve them from the machine. The information to be obtained from the machine after each operation shall include: operation time, number of remaining pieces in each reservoir, marked drawers, and a summary of the instruction parameters. The machine shall accept operator's instructions for packaging options through a keypad. The menus displayed on the LCD must be self-explanatory, and provide easy navigation for operators of various skill levels. The client requires that the machine be portable with no need for installations, 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 can be plugged into the AC outlet.

Operation

The machine is normally in standby mode. After loading the pieces and placing the cabinet in the machine, the operator enters on a keypad the packaging instructions, and then begins the operation by pressing a *<start>* button on the keypad. The entire packaging process must be done autonomously, and must take no longer than 3 minutes. Upon completion of the operation, all remaining pieces must be returned in their reservoir, and the packed cabinet be placed in the pickup area. Then, the machine returns to the standby mode by displaying a completion or termination message on the display. The operator can then pick up the cabinet, and communicate with the machine through the keypad and display to retrieve the operation information.

Depending on the operation time, packaging condition (pieces dispensed correctly, drawers closed), machine and delivery status (machine is in standby mode, remaining pieces returned to their reservoir, cabinet ready for pickup), and the 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 three separate but consecutive operations, and the total time, quality and accuracy 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 delivers the cabinet with a minimum of 3 drawers with pieces containing correct numbers and all drawers closed completely, returns to standby mode so that the cabinet can be unloaded normally, displays the completion or termination message at the end of its operation, and is able to communicate the operation information.

➢ Each "qualified" operation	+5000
➢ Each "complete" operation	+500
➢ Each drawer packaged "correctly"	+50
➢ Each drawer packaged "incorrectly"	–50
➢ Each marked drawer not empty	–500
➢ All drawers are closed "completely"	+500
➢ Each drawer not closed "completely"	–50
➢ Missing pieces in the reservoirs at the end of operation	–20 / piece
➢ Remaining pieces in the reservoir cannot be retrieved	–100 / reservoir
➢ "Damaged" cabinet	–200
➢ Cabinet is "unavailable" for pickup	–200
➢ Displayed number of remaining pieces is correct	+200 / reservoir
➢ Displayed number of remaining pieces is incorrect	–100 / reservoir
➢ Displayed marked drawers is correct	+500
➢ Operation time shown on the display is "correct"	+500
➢ Operation time shown on the display is "incorrect"	–500
➢ Displayed summary of instructions is incorrect or not shown	–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 +600
➢ Operability and Sustainability	0 to +600
➢ Elegance and Safety	0 to +600
➢ Dexterity	0 to +1000
➢ Extendibility	+800

- Compactness and Portability +800
- Real-time Date/Time Display +300
- Permanent Logs +300
- PC Interface +500

Constraints

a. The entire prototype (including the reservoirs while containing pieces and the cabinet when placed in the machine) shall completely fit within a $0.6 \times 0.6 \times 0.6\ m^3$ envelope at all operation times (power cable notwithstanding.)

b. The weight of the machine, including the empty reservoirs, power cable, etc., shall not exceed 7 kg.

c. The total prototype costs 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 8th, 2018, 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 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 reported.

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 can be plugged in the AC, 110V-60Hz, 3-pin outlet. Only one connection cable is allowed.

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 a keypad.

h. No installation or instrumentation is allowed in addition to what is devised within the machine.

i. The locations for supplying pieces and the cabinet and also the pickup location of the cabinet must be clearly specified in the machine.

j. Loading pieces and the cabinet, delivering the packed cabinet, and retrieving the remaining pieces must be convenient to the operator with no need for disassembling any part of the machine.

k. The time required for loading the pieces into the machine, entering the operator's instructions on the keypad, and starting the operation shall not exceed 1 minute. The number of supplied pieces must remain undetermined during the loading period, i.e., machine must not pre-count the pieces before the operation begins.

l. Each operation is considered "complete" when the correct type/number of pieces are dispensed into all drawers, remaining pieces are returned to their reservoirs, and the display shows a message indicating the completion of the process.

m. At the end of each operation, the machine display must be on prompt to show the following information per operator's request: operation time, number of remaining pieces in each reservoir, marked drawers, and a summary of the instruction parameters.

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

o. Each drawer is packaged "correctly" if all required pieces are dispensed in correct numbers; otherwise the drawer packaging is considered as "incorrect."

p. Each drawer is closed "completely" only if it is completely inside its compartment, to the referee's discretion.

q. Each piece (in the drawer, reservoir or machine) is considered as "damaged" if there are clear defects as a result of the operation, to the referee's discretion. The cabinet is considered as "damaged" if there are clear defects as a result of the operation, to the referee's discretion, e.g., obvious scratches or deformations, a drawer is detached, deformed, or cannot be opened/closed, etc.

r. The cabinet is considered "unavailable" for pickup if it is not completely located in the pickup place designated in the machine, or is jammed and cannot be removed from the machine.

s. The operation time is the duration between when the <start> button on the keypad is pressed and when the machine shows the 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 loading the pieces into the machine and entering the operator's instructions on the keypad before the operation shall not exceed 1 minute.

t. The recorded and displayed operation time is considered "correct" if it is equal to the time measured by the referee ±1 second. Otherwise, it is assumed "incorrect."

u. Each operation is "qualified" for scoring if, in addition to the lack of other disqualification factors (next constraint), the machine delivers the cabinet with a minimum of 3 drawers with pieces containing correct numbers and all drawers closed completely, returns to standby mode so that the cabinet can be unloaded normally, displays the completion or termination message at the end of its operation, and is able to communicate the operation information.

v. An operation is "disqualified" if any of the following happens to the machine or the team declares the termination. If the first or second 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 delivering the cabinet with minimum 3 drawers containing correct numbers and all drawers are closed completely, or
- does not display the termination or completion message on the LCD at the end of operation, or
- is not able to communicate with the operator after termination/completion of the operation, or
- runs longer than 3 minutes before terminating the operation, or
- takes more than 1 minute to load pieces and the cabinet in the machine and start the operation.

w. Each team will have a period of maximum 1 minute to set up the machine before it is ready to load pieces and the cabinet for each operation. (This time is extended to 2 minutes if the previous operation is disqualified.) If the preparation time exceeds 1 minute, the operation is "disqualified."

x. There will be no control over the conditions of the competition environment.

y. The machine must pose no hazard to the operator, and shall not be perceived as hazardous (e.g., excessive vibration, noise, sporadic movement, or electric sparks during the operation is 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 in a wide range of operating environments with a low failure rate.
- **Operability and Sustainability:** Little time/effort is needed to set up and calibrate the machine, 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 packaging and delivering the remaining pieces, being able to receive a cabinet with some of its drawers containing some pieces and empty those drawers before dispensing the instructed pieces, utilizing a secondary GLCD (in addition to the primary LCD) for delivering some useful information during or after the operation, etc.
- **Extendibility:** Machine can accept and package two cabinets in each operation with little or no need for modifications.

- **Compactness and Portability:** The entire prototype weighs no more than 3.5 kg (i.e., half of the maximum permitted weight,) and fits within a cubic envelope of $0.35 \times 0.35 \times 0.35\ m^3$ (i.e., ~20% of the volume of maximum allowed envelope.)
- **Real time Date/Time Display:** Date and time of each operation are displayed on the LCD in standby mode.
- **Permanent Logs:** Machine stores sorting logs of at least 4 previous runs in permanent (EEPROM) memory.
- **PC Interface:** The operation information, including sorting logs and date/time, can be readily downloaded from the machine to a PC.

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 structure and frames and incorporating whatever actuators and mechanisms required for the system. Major components of the Electromechanical subsystem can include: structure and frames, containers, piece positioning and dispensing mechanisms, drawer open/close mechanism, agitators (if needed), and sensors, microcontroller, and keypad/LCD mounting. 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 circuit 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 person must design and build at least one “open” circuit for a motor (DC, Stepper or servo) in the system and prove their functionality. Piece detection and counting (and possible shaft encoding) as well as detecting marked drawers are major sensory tasks of this subsystem, in addition to the driver circuits and cabling. The Circuit person 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 detecting Compartment 1, for transporting the fasteners to the box, for counting the fasteners, and for closing the lid. 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 ***"an ounce of application is worth a ton of abstraction."***