DESIGN AND DEVELOPMENT OF AN AUTOMATED, 4-ROW COTTON PLOT PICKER

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Abstract

An automated 4-row cotton plot picking system was developed for a John Deere 9986 cotton picker. The system uses a computer-controlled automation and data acquisition system to control processes and record data. The outer two rows from the six row picker were removed, converting it to a four row picker and weighing baskets were added to each of the remaining four rows, to independently allow for weights to be collected from each row of a plot. If samples are not being collected for turnout and fiber quality analysis, the system is a one-man operation. The design discussed resulted in substantial reduction of labor requirements for harvesting research plots, with median time per plot harvested equal to 58.2 seconds (or 29.1 seconds if two adjacent plots picked simultaneously). Use of the system during the harvests of 2018 and 2019 resulted in an average capacity of 106 plots picked and weighed per day (or 212 plots if two adjacent plots picked simultaneously).

Introduction

Systems for expediting harvest and weighing of cotton research plots, generally less than 30 m (100 ft) in length have existed nearly since the inception of mechanical cotton harvest. Brashears and Ray (1966) discuss a green boll separator and sacking attachment for a two-row cotton stripper, requiring a three- or four-man crew for operation: one man to operate the tractor, two men to bag the cotton samples, and one man (optional) to collect the green bolls. The stated harvest capacity of their system was 60 two-row, 15 m (50 ft) plots per hour; they cite a source as early as 1953, which discusses a cotton picker sacking attachment for small plot harvest. Kirk and Corley (1967) discuss an experiment evaluating the capacity of a similar design, with two sacking spouts that could be alternately employed to expedite harvest. Their time and motion study found times per 0.005 ac plot to be: 44.3 sec for one man operating the sacking attachment, 144.6 sec for one man gathering and sacking in the basket without a sacking attachment, and 76.0 sec for two men gathering and sacking in the basket without a sacking attachment. The one-man operation with the sacking attachment was 3.3 times as fast as the one-man operation without it and 1.7 times as fast as the two-man operation without it.

The systems discussed by Brashears and Ray (1966) and Kirk and Corley (1967) certainly improved the efficiency of cotton research plot harvest, but both systems still required that the sacked samples be tagged and weighed at a later time. Eaton (2003) discusses a system that overcomes this need to weigh the samples at a later time. The system that he described included a collector with a hinged bottom door and supported on weigh bars, which was mounted on the rear of a two-row cotton picker. Airflow from the picker was ducted along the top of the main basket to the collector. The system included a hydraulically actuated airflow diverter, which directed air away from the weighing collector when weights needed to be collected. Only one person was required to operate the system discussed, although a second person was required if grab samples were required. Eaton cites high labor requirements (six to eight man crews) for operation of sacking machines as one of the primary reasons for development of their plot picking system.
Cotton research plots harvested at Edisto REC prior to 2018 were picked with an older two-row plot picker similar to the design described by Eaton (2003). Not only was plot harvest time consuming because it was a two-row picker, but the harvester was substantially worn and down-time for repairs was at times equal to picking time in a given day, if not more than picking time. The two-row machine could be operated by one person by design, but two individuals were generally used to ensure proper operation. To keep up with research demand, support an increased plot harvest capacity, and to harvest research plots in a more timely manner, the four-row plot picker discussed in this paper was developed.

The specific objectives of this project were to: (1) reduce labor requirements, (2) improve efficiency of cotton plot harvest, (3) expand research capacity, and (3) replace a worn system/machine.

General System Description

The outer two picking heads of a six-row John Deere 9986 cotton picker were removed to effectively convert it to a four-row cotton picker. Four weighing baskets, one for each row to allow for varying plot configurations, were installed inside and at the top of the main basket. Cotton from each plot is ejected from the rear of each weighing basket to the main picker basket. If required, grab samples for turnout and/or fiber quality can be manually collected from the weighing baskets prior to ejection. The system can be broken down into four major design components, which are discussed below: software and user interface, weighing system and baskets, picking air control system, and electrical controls.

Software and User Interface

The software for operation, automation, and data collection of the Clemson Cotton Plot Picker (CCPP) system was developed using vb.net in Microsoft Visual Studio 2013 for operation on Microsoft Windows Operating Systems. The system, as installed operates on a Panasonic CF-19 convertible Toughbook, in tablet mode. The program follows the basic control loop shown in Figure 1 and discussed below.

Figure 1. Program control loop for the CCPP.

The program loads to the Setup Screen (Figure 2), where timings are set, and automation mode is selected. Selection of automation mode from the provided dropdown simply toggles the appropriate Skip, Auto, and Require checkboxes shown in Figure 2. Fully automatic mode requires operate input to signal that plot harvest is complete and to enter next plot ID(s). Manual model requires operator input for each step of the cycle. Semi-automatic mode is the same as fully automatic mode, but also requires operator confirmation of weights and tare weights. Semi-automatic, sampling mode is similar to semi-automatic mode, but also requires operator to prompt for initiation of cleanout air after basket doors are opened. From the Setup Screen, some of the timings can be adjusted, the plot plan can be loaded, the weighing baskets can be tared, and the log file can be named.

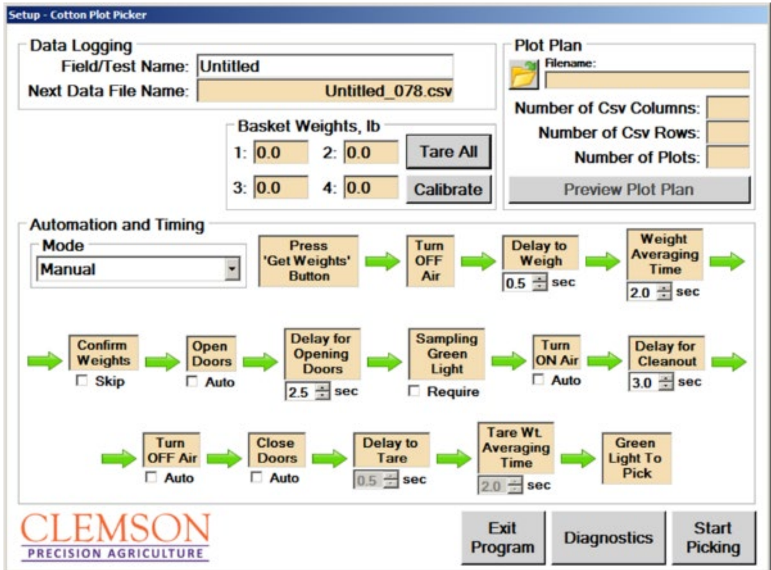


Figure 2. Setup Screen for the CCPP, which loads on program startup.

Plot plans can be uploaded as comma separated values (CSV) files, allowing the operator to select the next plot to be harvested, rather than typing each plot's ID. When the plot plan is loaded, a preview can be displayed, such as the one shown in Figure 3. The screen shown in the plot plan preview, is the same screen shown when in harvest mode. As plots are selected/assigned/logged, the cells on the plot plan are highlighted accordingly, using the key at the bottom of Figure 3, so the operator can easily keep track of his location in a given test.

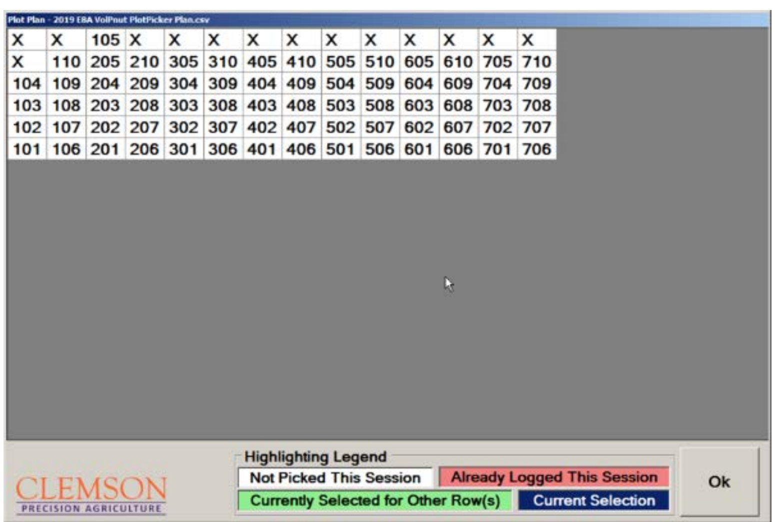


Figure 3. Uploaded (CSV) plot plan preview.

The Diagnostics Screen (Figure 4) can be accessed from a button at the bottom of the Setup Screen. The primary functions included on the Diagnostics Screen include inputs and outputs for testing and exercising the mechanical systems on the CCPP. Buttons are provided so that each weighing basket ejection door can be manually opened and closed, to check their operation or for servicing. The numeric up/down input labeled "Delay for Opening" is provided because the system does not employ "Door Open" switch inputs. "Door Closed" switch inputs are provided on the ejection door of each weighing basket and their operation can be evaluated from this screen as well. The Green Button and Red Button inputs are included for communication with the operator by individuals collecting grab samples from inside the main basket. The buttons to control toggling of picking air and exhaust air are included for cycling the valves, discussed later, to check their operation. Valve cycle time, to control automation sequence, is manually input by the user from this screen as well.

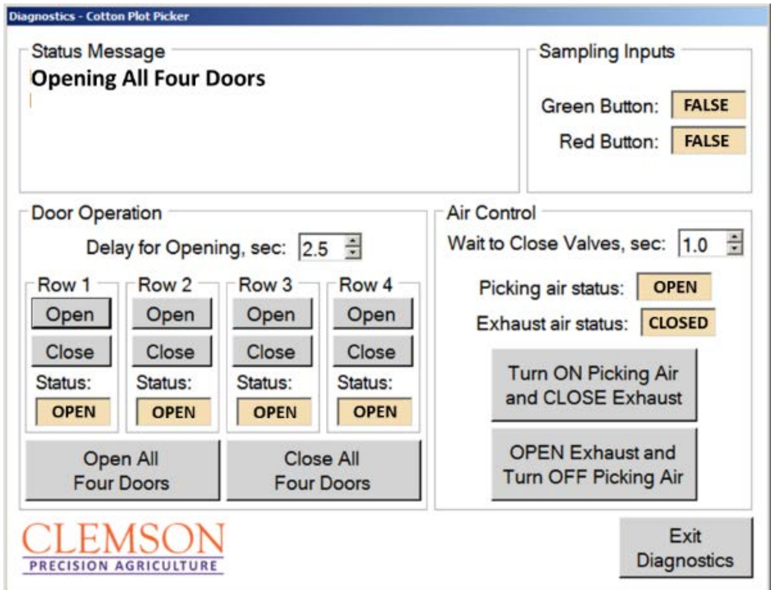


Figure 4. Diagnostics Screen for checking and exercising mechanical system operation.

Also, from the Setup Screen, the Scale Calibration Screen can be accessed (Figure 5). Each weighing basket is calibrated independently from two weights. Calibration is performed as linear regression between load cell response at low weight and load cell response at high weight. Typical calibration weights are 0 kg (0 lb) and 9 kg (20 lb), net weigh. Calibration of all four baskets takes less than five minutes. While it is probably acceptable to re-calibrate once daily or even less often, we generally calibrate every time we move fields, since the time to calibrate is so small.

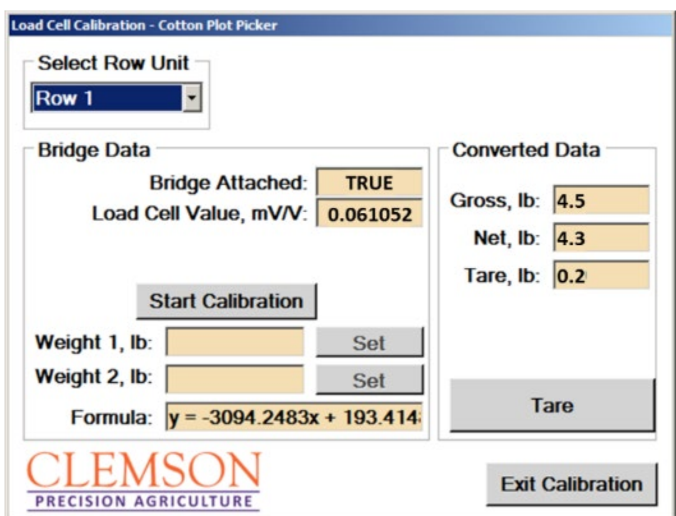
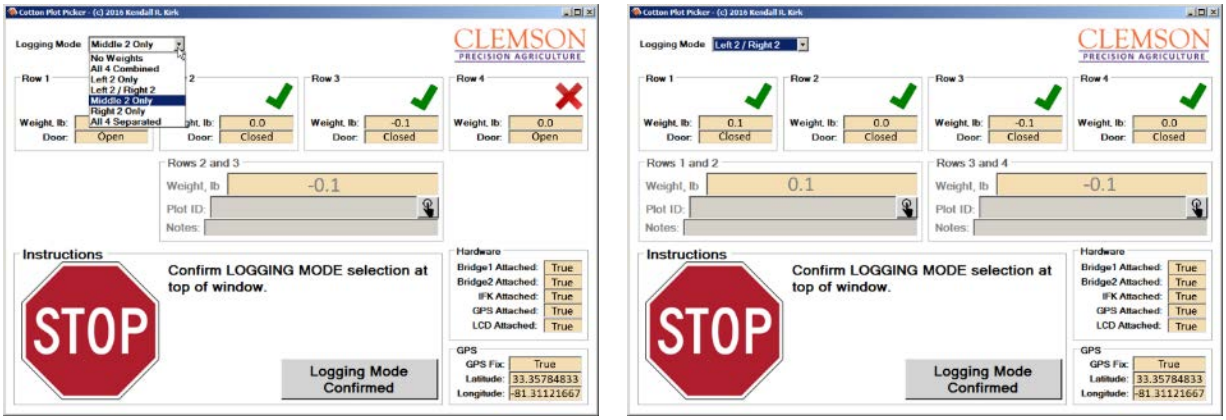


Figure 5. Scale Calibration Screen for the CCPP.

After all of the Setup Screen options are defined, the operator clicks the Start Picking button on the Setup Screen, which brings him to the Picking Screen (Figure 6), where he must select from seven logging modes: No Weights (for bulk picking; all four weighing basket doors are held open), All 4 Combined (for four-row plots; all four basket weights are summed into a single weight), Left 2 Only (for one, two-row plot; left two basket weights are summed into a single weight, right two basket doors are held open), Left 2 / Right 2 (Figure 6b, for two, two-row plots; left two basket weights are summed into a single weight and right two basket weights are summed into a second weight), Middle 2 Only (Figure 6a, for one, two-row plot; middle two basket weights are summed into a single weight, outer two basket doors are held open), Right 2 Only (one, two-row plot; inverse of Left 2 Only), and All 4 Separated (four, one-row plots; each basket weight is recorded/output as an independent plot weight). After selection of logging mode, the operator is prompted to engage the fan control of the picker.



(a) (b)

Figure 6. Picking Screen showing selection of logging mode with examples for: “Middle 2 Only”, for one, two-row plot where the middle two basket weights are summed into a single plot weight and the outer two basket doors are held open (a); and “Left 2 / Right 2”, for two, two-row plots where the left two basket weights are summed into a single plot weight and the right two basket weights are summed into a second plot weight.

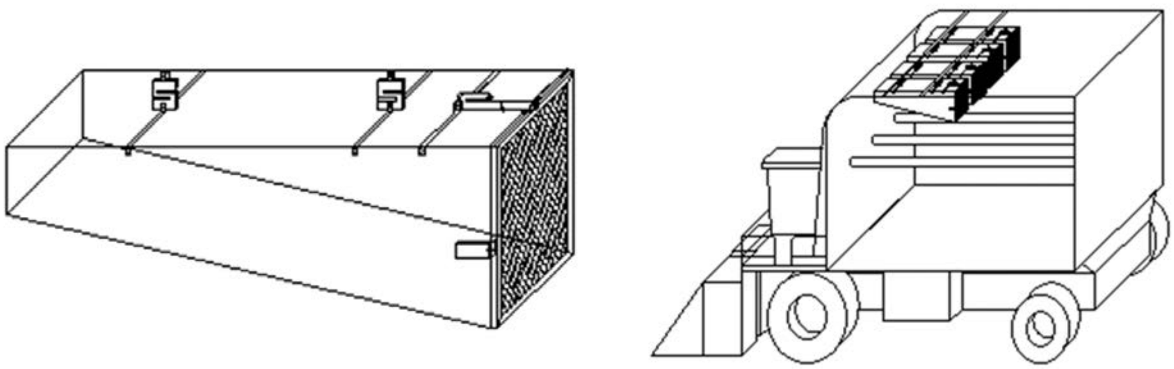
After the operator has indicated that the picker’s fan is engaged, the program loop shown in Figure 1 begins, with the Tare step. For taring, the software closes the air to the basket and opens the exhaust air, so that air flow does not affect the tare reading. More discussion on airflow control is provided in a later section. The baskets are then tared, averaging weights for the timing assigned on the Setup Screen; in windy conditions, averaging time can be increased to reduce errors. After the basket weights have been tared, the operator is prompted to enter or select the plot ID(s), the picking air [to the weighing baskets] is opened, and the exhaust air is closed. The operator is prompted with a “GO. Clear to start picking.” message and provided with a button for input to indicate that he is done harvesting the plot and ready to get weights. Aside from entry of Plot IDs, this is the only operator input required in Fully Automatic Mode.

Once the operator has indicated that he is ready to get weights, the software opens the exhaust air and closes the picking air [to the baskets] so that an accurate weight can be obtained. Weights are collected, based on the weight averaging time specified on the Setup Screen, and weights are displayed for operator acceptance or rejection, except in Fully Automatic Mode, where acceptance and rejection is bypassed. If the operator rejects the weights, the baskets are re-weighed in a loop until they are accepted by the operator. After acceptance of the weights, the weights are recorded into the log files, discussed in more detail later. In Manual Mode, the operator must click a button to open doors for cleanout, otherwise the doors are automatically opened. In Manual Mode or Semi-Automatic Sampling Mode, the operator must then click a button to turn on the cleanout air (and close the exhaust air), otherwise, this step is automatically completed. Prior to turning on the cleanout air, a grab sample can be manually collected by an individual working inside the basket (or by the operator, upon entry to the basket).

Once the cleaning air is turned on, the exhaust air is closed. A countdown timer for operation of cleanout air (specified by the user on the Setup Screen) elapses, ideally providing sufficient time for basket cleanout. In Manual Mode, the operator must then click a button to close the basket doors; in any other mode, the doors are closed automatically after the countdown timer for cleanout is completed. AgCam video cameras (Dakota Micro, Inc.) are installed in the main picker basket, directed at the weighing basket doors, and with a display that the operator can view from inside the cab to confirm proper operation and adequate basket cleanout. At this point the operator has the opportunity to change logging modes, if desired. Once the basket doors have been returned to the closed position the program loop has been completed. The loop will return to the start and the operator can begin with the next plot.

Weighing System and Baskets

The weighing system consists of four identical baskets (Figure 7), constructed of sheet metal and installed inside, at the top of the main basket on the picker. Key components of each basket include: two Phidgets (Calgary, Alberta, Canada) model 3138_0, 100 kg (220 lb) capacity S-type load cells; a Surplus Center (Lincoln, Neb.) model 5-1845-2, 1.96 in. stroke, 110 lb, 12 Volt DC linear actuator; and a Phidgets model HIN4208_0 button type limit switch to indicate door closure. The load cells are rigidly mounted to the top of the baskets, along the centerline of each basket, and fixed to the top of the main basket with a pivoting attachment allowing them to swing left and right, reducing stresses on the load cells when the basket is pivoted for offloading. The front of each basket is open and positioned so that cotton flow ducted from the picking head is directed into the basket; round stock "fingers" are positioned to assist in flow of seed cotton into the basket. The door creates the back of each basket and is constructed of an angle iron frame with an expanded metal covering to assist in air release. The doors are hinged on the top side and the linear actuators are mounted on top of each basket, allowing about 90 degrees of door rotation about the pivot for the opening operation.



(a) (b)

Figure 7. Schematic of a weighing basket (a), showing the open end oriented towards the front of the picker to the left side, as depicted, and the door and actuator oriented towards the back of the picker to the right side, as drawn, with two lead cells and linear actuator for door operation shown on top of basket; and schematic showing general mounting position of weighing baskets in main picker basket (b).

Final weighing basket geometry resulted from some trial and error. An earlier basket design was constructed as a rectangular prism of expanded metal. This basket failed to allow cotton to be ejected because the cotton tended to be mechanically held in place by the expanded metal. Insertion of a smooth, sheet metal sleeve improved this design, although the cotton tended to bunch and choke off the air flow during the plug flow process required for cotton ejection. The sloped, trapezoidal design in Figure 7a addressed this and also provided some benefit of gravity and an inclined slope for ejection of the cotton. Anthony (1994) reported settled seed cotton density to be 48 kg m^{-3} (3 lb ft^{-3}), but measurements from our early basket designs suggested seed cotton density for our system to be about half of that value, perhaps from entrained air, at 26.6 kg m^{-3} (1.66 lb ft^{-3}). This required us to approximately double the size of our baskets from the original design, which was another reason for adopting a trapezoidal cross section. Lengthening the baskets from the original design was also required. A picture of the baskets, viewed from the rear, as installed can be seen in Figure 8.

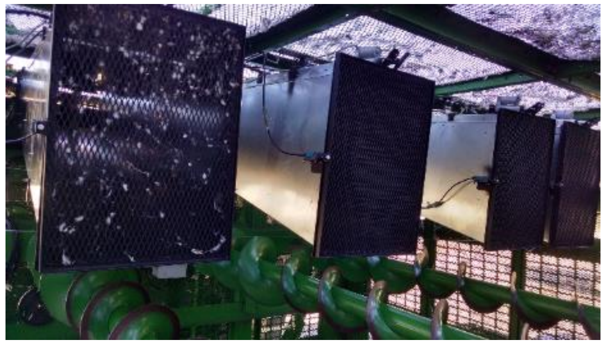


Figure 8. Final design of weighing baskets, as installed, showing linear actuator at top of each basket for door operation and limit switch at left side of each basket for indication of door closure.

Picking Air Control System

The air system utilizes a pair of Airtac model 4V210-08, 5 position, 2-way single solenoid valves controlled by the software for operation of the picking and exhaust air (Figure 9). Two, independent valves are required so that when the exhaust air needs to be closed, the picking air can first fully open, and vice versa. This prevents hoses connected to the picking heads from blowing out or otherwise being compromised. Each solenoid valve provides pressurized air flow from a ViAir model 380C, 200 psi, 1.58 cfm, continuous duty, 12 Volt DC air compressor to a bank of Parker model 2.00DXPSR06.0 pneumatic cylinders. Each cylinder operates a custom built actuation mechanism to open and close the gate on a Nordfab model 3240-0600-100000, 6 in., manual, blast gate. The blast gates controlling air delivery to the picking heads are installed between the picker fan and each picking head and the blast gates controlling exhaust air delivery are mounted on the air lines that formerly supplied air to the picking heads for the outer two rows on the picker, which have been removed in conversion to a four-row picker, as discussed. Pictures of the air compressor and three of the blast gates, as installed can be seen in Figure 10.

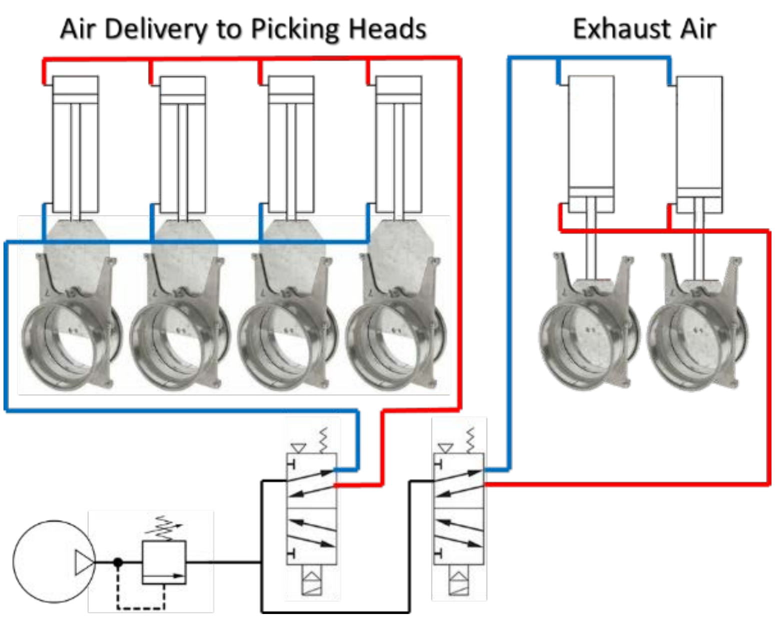


Figure 9. Pneumatic control circuit for operation of picking and exhaust air.

(a) (b)

Figure 10. Air compressor for supplying air to the pneumatic control circuit, as installed (a), and view from the right side of the picker (b), showing two blast gates (left) for controlling airflow to the outer two picking heads on the right side of the picker and one blast gate (right) for controlling exhaust air. Note in image that the blast gate for the exhaust air is closed and the blast gates for the picking air are open.

Electrical Controls

The electrical controls utilize a Phidgets model 10109_1 input/output board to interface via USB with the laptop operating the control software. This board provides eight digital inputs, eight digital outputs, and eight analog inputs (not used in this application). The control circuit utilizes five Phidgets model 3051_1 dual relay boards for basket door operation and solenoid operation for the pneumatic control circuit. Each linear actuator utilizes two relays for operation, which invert the polarity provided to the actuator motor. The fifth relay board utilizes one relay for control of the picking air and one relay for control of the exhaust air. Each pair of load cells is connected in parallel and connected to a Phidgets model 1046_0 USB-interface bridge board. An LCD display (Figure 11) is also provided and mounted inside the main picking basket so that when the operator identifies the plots to be picked, individuals collecting grab samples in the picking basket can confirm/verify plot IDs for sample labelling.

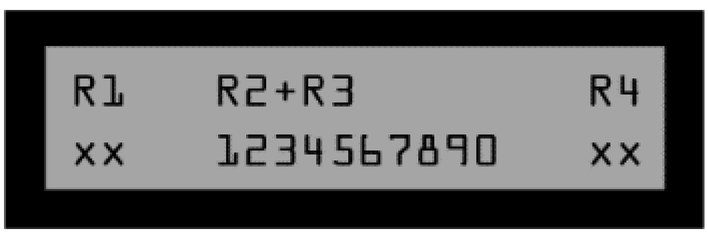


Figure 11. LCD display mounted inside picking basket, showing an example of what would be displayed if the logging mode was set to be Middle 2 Only and the plot ID entered by the operator was 1234567890.

Conclusion

The plot picker described here has worked satisfactorily for two harvest seasons to date (2018 and 2019). Median in-test picking time across these two seasons has been 58.2 seconds per plot if one plot is picked at a time or 29.1 seconds per plot if two, adjacent plots are picked simultaneously. When considering field efficiency (turning time, travel time between tests, setup time, etc.), mean picking time was 120 seconds per plot if one plot is picked at a time or 60 seconds per plot if two, adjacent plots were picked simultaneously. The system has demonstrated capacity to pick an average of about 104 plots per day if one plot was picked at a time or 208 plots per day if two plots were picked at a time. At the completion of each plot no additional time is need for sample removal from picker for weights.

References

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