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DEVELOPMENT OF AN OPERATOR FEEDBACK SYSTEM FOR THE MODULE BUILDER

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Abstract

Cotton quality during storage can be maintained by constructing modules with shapes that prevent water from collecting on the cover and using covers that resist water penetration. Because covers are susceptible to tears, weathering, and other defects, it is necessary to build properly shaped modules to maintain a higher level of seed cotton quality.

Previous research has shown that the compressed height of seed cotton is directly related to the mass of seed cotton. This led to the design of an operator feedback system for the module builder based on sensing the location of the carriage and the tramper foot. Ultrasonic sensors and targets were installed to determine the position of the carriage and tramper foot. This system was installed on a module builder to evaluate its accuracy and identify the nature of errors that occurred. The shape of the compressed seed cotton was displayed graphically as a feedback signal to the operator.

The system correctly identified between 75-80% of the compression strokes over the half of the module nearest the ultrasonic carriage sensor. Performance degraded severely at the far end due to the presence of multiple reflectance paths. The height of the displayed columns appeared to correctly represent the minimum tramper height and the height of the module. Different sensing techniques for determining carriage location, improved noise filtering, and more accurate detection of when the carriage is stationary are needed. However, the system showed promise for operator guidance and improving the shape of seed cotton modules.

Introduction

The economic impact of poorly formed modules has been quantified by several researchers. A survey of 646 modules in Texas gin yards during the summer and fall of 2003 indicated that 50% of the modules had depressions in the top surface where water would collect (Simpson and Searcy, 2004). Laboratory testing also showed that many covers (regardless of condition) will allow much greater penetration of water if rainfall collects on the module surface rather than running off.

Higher moisture contents will adversely affect the quality of cotton lint and seed. Curley et al. (1988) found that color, particularly yellowness (+b), was significantly affected by the module moisture content. At a moisture level of 13 to 14%, the yellowness of the lint began to increase rapidly. Several researchers have demonstrated that quality degradation in a module is often localized, providing evidence that module shape and cover quality have a significant effect on lint and seed quality (Hardin and Searcy, 2005).

Simpson and Searcy (2005) studied modules ginned in fall 2004 in the Texas High Plains, which had an unusually long period of rainfall while many modules were waiting to be ginned. Modules were classified according to the quality of their construction and the condition of their cover. Poorly built modules, even with a good quality cover, had an average lint loan value of $242 less than well constructed modules with a cover in good condition. The lost value due to poor construction was similar when comparing modules with a low quality cover.

Building modules that will shed rainfall is often difficult. Modern harvesting equipment and practices provide less time for the module builder operator to properly distribute cotton. The tramper foot was designed to compress seed cotton; consequently, it is not an efficient device for moving cotton in the module builder. Additionally, since the seed cotton will expand after the module is built, determining the module shape that results from a given sequence of distribution and compression actions is difficult for the operator. Development of a system that provides the module builder operator information about the ***final*** shape of the module would have great value in building modules with a crowned surface.

Hardin (2004) demonstrated that seed cotton was compressed to a constant density with a constant force, regardless of the mass of seed cotton. Therefore, the height of a laterally constrained volume of seed cotton under compression is proportional to the mass of cotton. This research also showed that a greater mass of seed cotton will have a greater final height as well. These results were used as the basis for the operator feedback system. Measuring the compressed height of the seed cotton along the length of the module builder provides estimates of the relative mass of seed cotton at different locations in the module builder and the resulting module shape.

The design of this feedback system was first described by Hardin and Searcy (2005). Ultrasonic sensors were used to sense the carriage and tramper foot locations. Processing was done with an 8-bit microcontroller, and the estimated final module shape was displayed on a graphic LCD screen.

System Development and Testing

The algorithm for determining when a compression stroke occurs was modified from the previous version. Filtering of the sensor data was performed by using an exponentially weighted moving average of the sensor values. A weight of 0.4 was used for the current sensor reading. This value was determined by examining data collected in the Southern High Plains in February and the Brazos Valley in September. Detection and removal of outliers was also implemented. The threshold for considering a sensor reading an outlier was based on the maximum distance the tramper or carriage could move in one sampling period, 0.1 s, and verified using the previous data. The chosen outlier thresholds were ± 48 cm from the last smoothed value for the tramper foot and ± 84 cm for the carriage. These smoothed values were used for all subsequent processing.

A tramping event was indicated by a minimum downward tramper foot movement of 45 cm, followed by an upward movement of at least the same magnitude, all while the carriage was stationary. To determine when the carriage was stationary, the smoothed value had to remain within a movement threshold of ± 17 cm to account for sensor noise. The system timing was also corrected, so the sensors were sampled at the desired rate of 10 Hz. Previous versions were designed to sample at 10 Hz; however, a programming error resulted in unnecessary oversampling.

When a tramping event was identified by the microcontroller, a column was displayed on the LCD screen. The screen width was divided into thirty equal segments of eight pixels, each corresponding to approximately 30 cm of carriage travel. The stationary location of the carriage determined at which of the thirty positions the column was displayed. The left side of the screen represented the end of the module closest to the operator. The height of the displayed column corresponded to the minimum tramper height at this stationary carriage value. Each pixel of height represented 3 cm of height, with a zero height column corresponding to full extension of the tramper foot.

If multiple compressions occur in the same location without the carriage moving, the system displays the smallest minimum height achieved during the tramping actions. When the carriage moves to a location where tramping previously occurred (i.e. after more cotton is loaded in the module builder), the existing column is replaced by a new column corresponding to the new minimum tramper height. The resulting display should therefore represent the final height of the module when viewed from the side (figure 1).

Figure 1. Simulated display of a finished, well-formed module.

Using this improved software version, eight modules were built using a module builder with the system installed in the Lubbock area in November 2005. All sensor readings, along with values where carriage movement was detected were transmitted to a computer over a wireless Bluetooth serial port connection for analysis. The values had a unique status bit to indicate whether they were sensor readings or carriage movement values resulting in a display or no display. This data was analyzed to determine the percentage of compression strokes that were correctly identified and the nature and frequency of the errors that resulted in no display of tramping actions. Observations of the utility and potential drawbacks of the system were also made.

Results and Discussion

Two types of display errors are possible; not displaying the minimum height resulting from an actual compression stroke, or displaying a column incorrectly. Table 1 displays the results of analyzing the data from the eight modules.

Table 1. Accuracy of feedback system.

Number of Compression Strokes	1914
Number of Columns Displayed	1189
Number Displayed Correctly	1129
Percent of Displayed Columns that are Correct	94.95%
Percent of Strokes Displayed Correctly	58.99%

Understanding the conditions that result in these errors is necessary to improve the performance of the feedback system. Two sources that collectively accounted for over half of the display errors are the presence of multiple reflectance paths and loss of the actual carriage location due to outlier removal following a multiple path event. Figure 2 shows the sensor readings and smoothed values typical of these error sources.

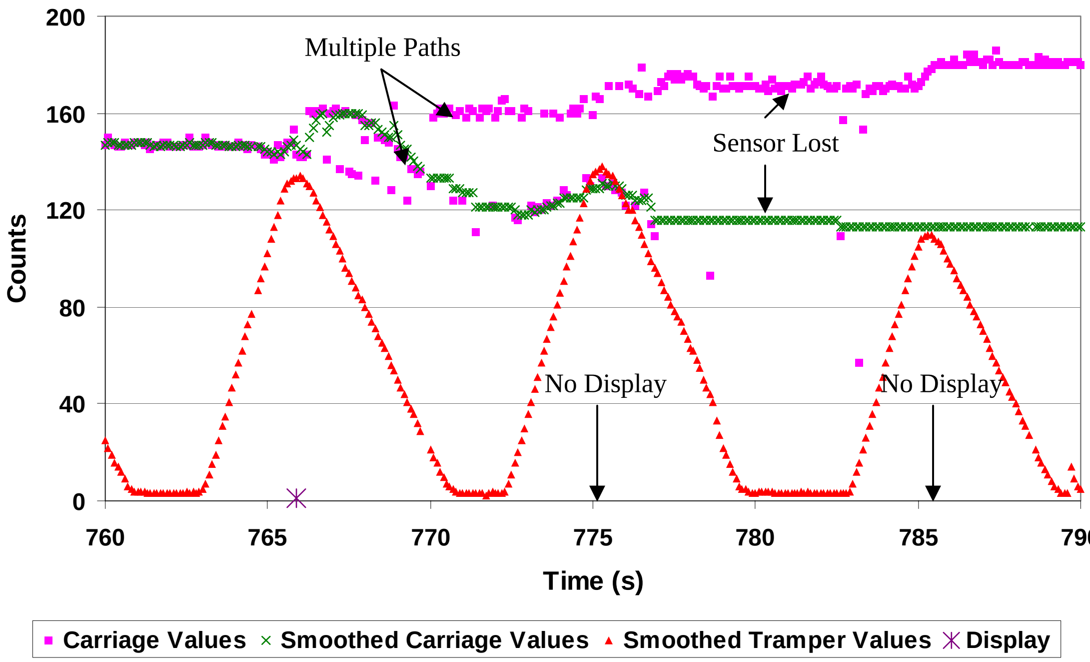

Figure 2. Multiple path and lost sensor errors.

Another potential cause of losing the true carriage position was detection by the carriage sensor of the harvester basket during unloading when the carriage remained at the far end of the module builder. Generally, the harvester basket location would be considered an outlier; however, system noise and movement of the basket occasionally resulted in its detection. The effect of this action would be that the initial tramping actions at the far end of the module builder could be missed if the carriage was not moved to the last sensed position of the harvester basket.

Another significant source of error is sensor noise, accounting for over a quarter of all errors. Sensor readings that differed greatly from the smoothed values were eliminated as outliers as detailed above; however, carriage sensor values within this outlier threshold could change the smoothed value enough that the algorithm interpreted the reading as carriage movement. This event is shown in figure 3.

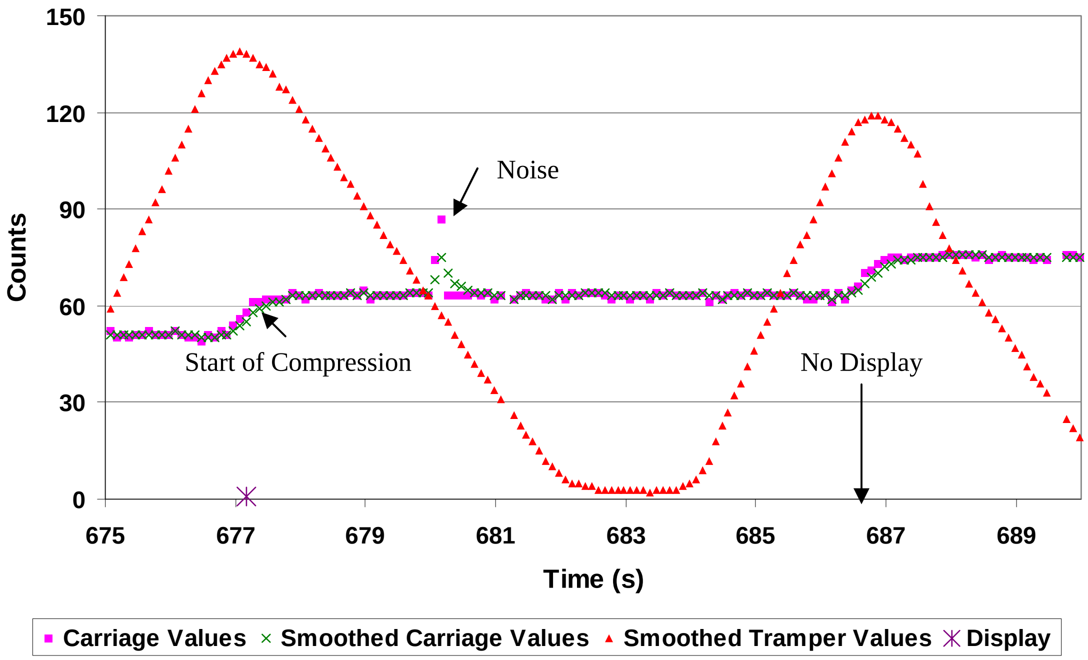

Figure 3. Noise error.

A third type of error occurred when the algorithm had determined that the carriage was stationary before it actually was. This error occurred when the identified value differed from the actual stationary value by approximately the carriage movement threshold. The normal variation observed in the sensor readings resulted in the movement threshold being crossed during the tramping action. Figure 4 shows this error.

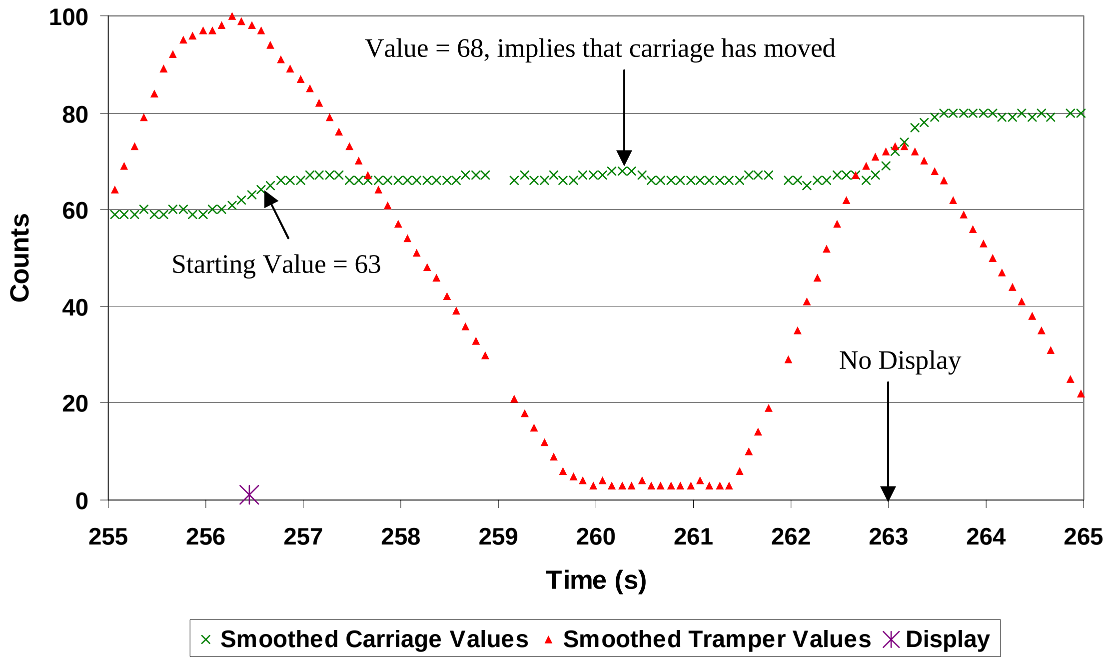

Figure 4. Carriage movement threshold error.

A final significant, but smaller cause of errors was the failure to attain the minimum tramper foot movement required to consider an operator action an actual compression stroke. This requirement was occasionally not met on the final passes across the module, as the tramper foot was not raised 45 cm. The other reason for not achieving this threshold was due to a large increase in the tramper sensor value, with that value and subsequent ones classified as outliers, as detailed in figure 5.

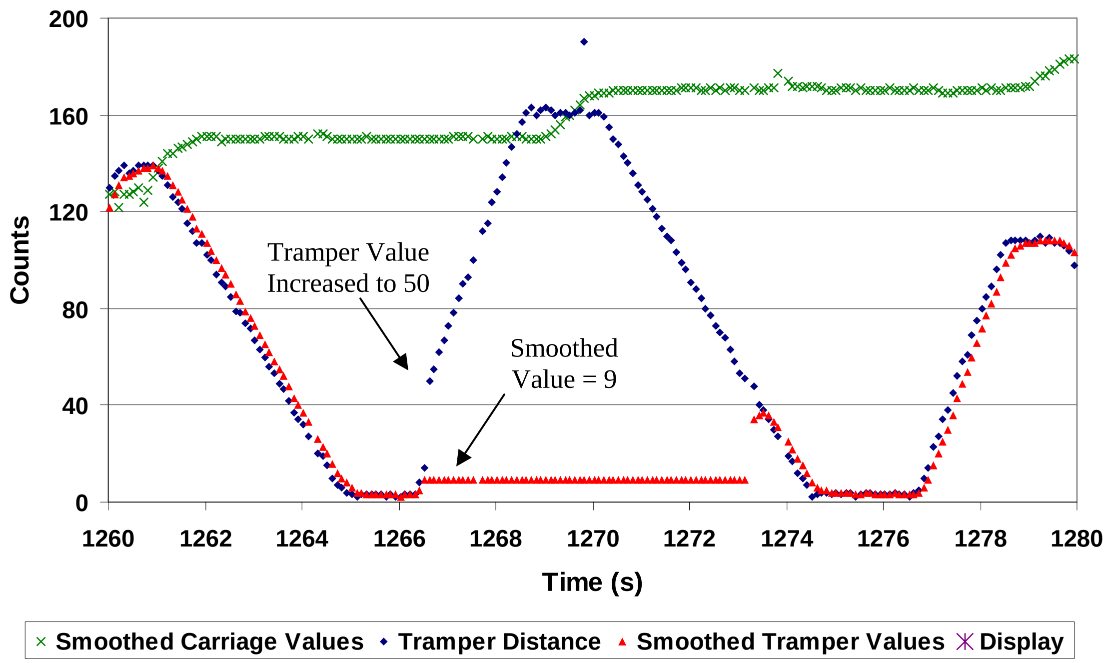

Figure 5. Tramper movement threshold error.

The relative frequency of these errors is shown in figure 6. Clearly, eliminating or significantly reducing the multiple path (and consequently, the lost sensor) and noise errors would greatly improve the performance of the system, as these sources account for 80% of the errors.

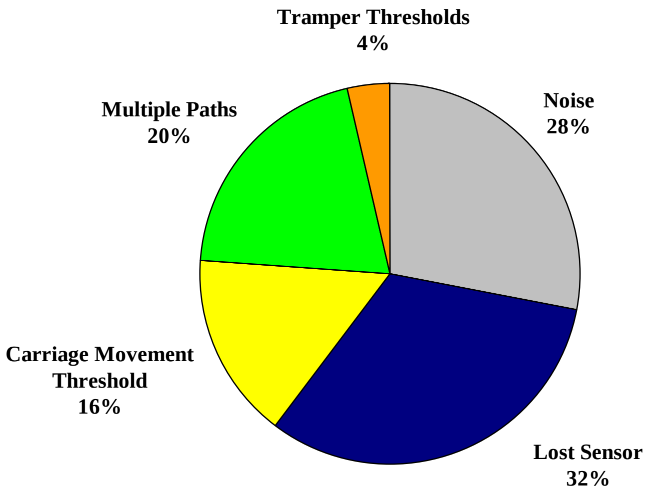

Figure 6. Error causes.

Because the system performance was observed to degrade towards the far end of the module, the error sources were examined by carriage location. The module builder length was divided into five equal sections, approximately 1.76 m long, and the compression strokes in each region were classified as correctly displayed or as an error due to one of the above sources. These results are displayed in figures 7-11. While only 82% of compression strokes were correctly identified in the first section of the module builder, a column was usually displayed at some point after every basket load because several passes (at least 3) were made over the same location. Clearly, the percentage of compression strokes correctly identified decreased with increasing distance, with a sharp decline in performance between the third and fourth regions.

This decline was primarily due to the increase in the multiple path error and the associated loss of the carriage location. One reason for this increase in frequency was misalignment of the ultrasonic sensor with its target area. Slight misalignment will not cause significant errors at shorter distances; however, this condition becomes problematic at larger distances. Another factor that exacerbated this problem was movement of the various components of the module builder. As the tramper foot is extended, the carriage is lifted up. When the module builder is lifted off the ground, the frame may flex slightly, compounding any initial misalignment. Wind also has the ability to deflect the ultrasonic signal.

The fraction of errors due to noise, the carriage movement threshold error, and not meeting the minimum tramper movement distance did not change significantly throughout the module. It should be noted, however, that even if the multiple reflectance path errors and the loss of the actual carriage location by the algorithm were corrected, some of those compression strokes may still not display to other sources of error. Due to this result, the actual problems with noise and thresholding errors may be larger at the far end of the module builder.

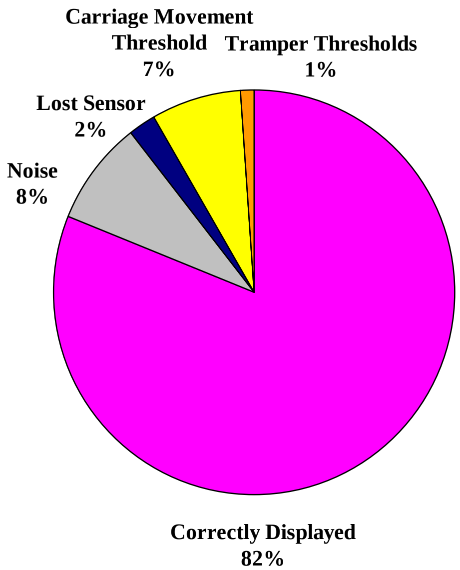

Figure 7. Compressions from 0-1.76 m.

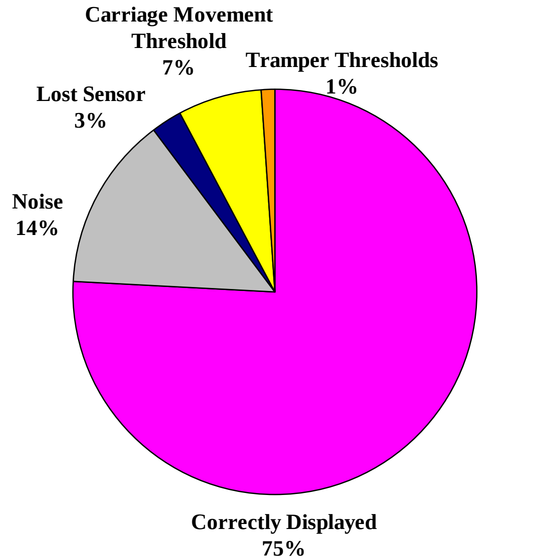

Figure 8. Compressions from 1.76-3.52 m.

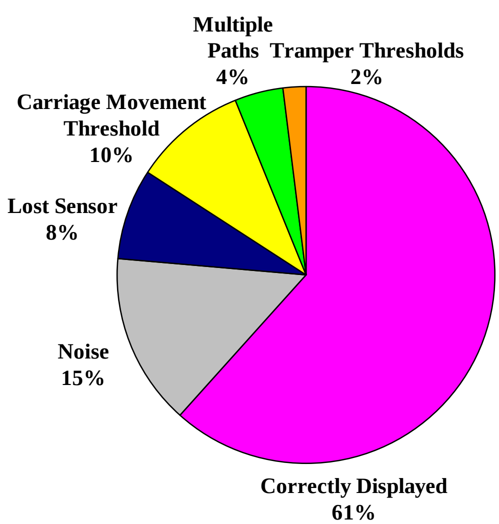

Figure 9. Compressions from 3.52-5.28 m.

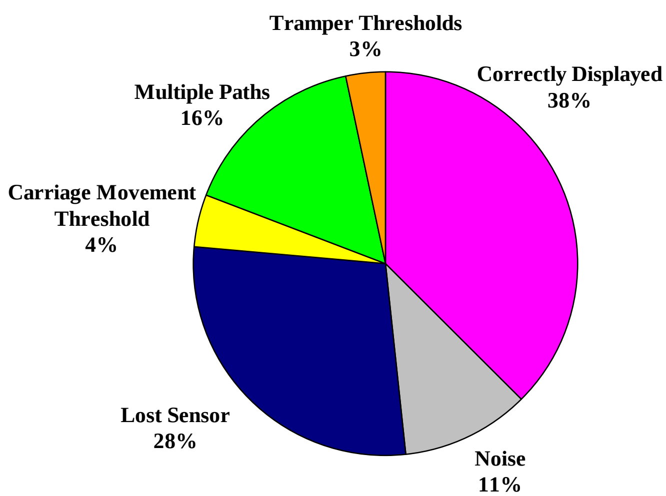

Figure 10. Compressions from 5.28-7.04 m.

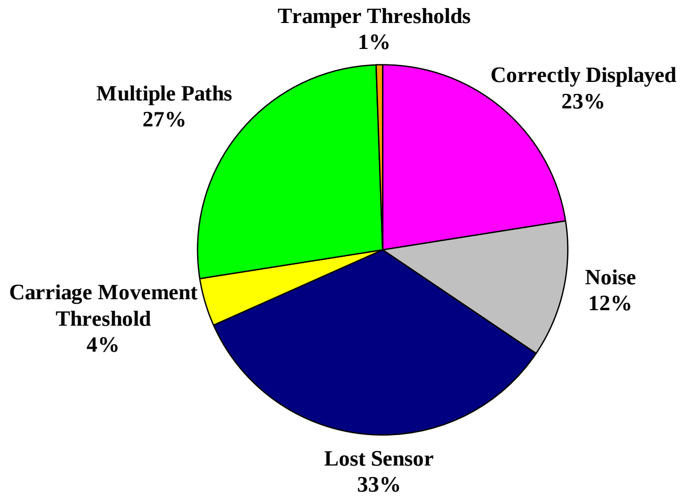

Figure 11. Compressions from 7.04-8.8 m.

Tramping in the first half of the module (closer to the operator and sensor) usually resulted in a displayed column. However, at the more distant end of the module builder, the feedback system frequently lost the carriage location. This loss of accurate carriage position was characterized by the arrow on the display indicating the carriage location remaining stationary, despite moving the carriage. This error was presumed to occur due to sensing incorrect values, followed by outlier detection, which ignored the correct carriage location values. The height of the displayed columns appeared to correctly represent the tramper foot height during compression and the height of the module. The system performed as designed with regard to distribution actions, as no columns were displayed.

The feedback system can not provide useful information until the tramper foot can not be extended fully. Occasionally, when the tramper was extended fully, a column one or two pixels high was displayed since the minimum smoothed value was greater than the actual minimum tramper height. During testing the tramper foot was not extended fully after the fourth harvester basket load. Once the module contained enough cotton, the maximum force was generated and the minimum tramper height was greater than the height at full extension.

The system was useful for identifying regions with differing amounts of seed cotton over the first half of the module, where the carriage position could be accurately sensed. This allowed the operator to move cotton from the regions of more mass into areas with less cotton. The system was also useful for determining locations that had not been compressed since the last load of seed cotton. Once the tramper foot can not be extended fully, the difference in column heights between loads is large enough that areas that have not been compressed can be easily distinguished from areas that have.

However, the module length corresponding to each display column, 30 cm, may be too small. The actual distance between successive tramper strokes was often 45 to 75 cm. The distance that the width of each display column corresponds to should be the optimal distance between tramping strokes, based on building a well-formed module in an efficient manner. Currently, no studies have been done to determine the optimum tramping pattern. However, this system could prove useful in studying this aspect of the module building process.

In the final compression strokes over the module, the seed cotton is sufficiently compressed that the operator does not have to raise the tramper foot as high to move the carriage to the next position. The actual distance between the maximum and minimum tramper foot height was often around 30 cm, as opposed to the 45 cm threshold used. As a result, the current algorithm did not record these as true compression strokes. This tramper height threshold could be reduced without effecting performance. Alternatively, the algorithm could incorporate an adaptive threshold that decreases in magnitude with increasing amounts of seed cotton.

Conclusions

The feedback system provided useful information to the operator over the first half of the module as the tramper foot sensor consistently and accurately sensed height. However, the sensing of the carriage location was less reliable, particularly at greater distances due to the presence of multiple reflectance paths. This system has the potential to aid operators in building modules with a more desirable shape and could also be interfaced with a module builder automatic control system to direct the system to move cotton to appropriate locations. However, sensing of the carriage position must be improved.

Ultrasonic sensors were used due to their low cost and adaptability to different module builders. This sensing technology has been proven adequate for determining tramper foot height. Replacing the carriage sensor with a magnetic or inductive proximity sensor mounted on the carriage drive shaft or sprocket should remedy many of the problems encountered in testing. A proximity sensor would not be affected by misalignment or wind. Additionally, these sensors are also inexpensive and would be adaptable to different module builders since rotary power is used to drive the carriage, regardless of module builder manufacturer. By avoiding the multiple path errors and related problem of losing the carriage location, the system accuracy would likely be in the 80-85% range observed in the near end of the module builder (Figure 6). More robust methods will still be required for noise filtering and correctly identifying when the carriage has stopped moving so that the system accuracy will be high enough for widespread use and acceptance.

Acknowledgements

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