ME450 - Winter 2014 Term
The University of Michigan: Mechanical Engineering
Team 19

# Open-Source Linear Book Scanner

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**ABSTRACT**

Digitizing books and documents has become increasingly prevalent amongst libraries and university facilities as large data storage becomes cheaper and more available and physical storage space becomes scarce. There are currently many commercial scanning methods available, but all but have trade-offs between speed, reliability, automatic page turning and price. The cost of even the most basic scanners is quite significant and prohibitively expensive to smaller libraries and facilities. To alleviate this problem, Google began an open-source book scanning project whose goal was to develop a prototype that is of reasonable size, fully automatic, and can be easily manufactured within the budget of a small library. Since 2012, three prototypes have been built in an attempt to satisfy these requirements. Each iteration of the design has implemented a new variation on the idea of pneumatic page turning. This involves the use of a vacuum to pull book pages into a channel that flips them to the other side of the book. The purpose of this report is to present the design process and final plans for the fourth generation of the linear book scanner prototype, as developed by ME450 Winter 2014 senior design Team 19.

**BACKGROUND**

Libraries have traditionally been limited by the number of individuals they can reach, space for physical text storage and the challenge of finding the specific information requested by a user [1]. All of these problems can be solved by storing information digitally, as texts can be kept in a small space at a low cost, are protected against physical damage, and can be made searchable. This idea led to a “mass digitization” initiative by Google in 2004 called Google Books, which involved partnerships with five universities including the University of Michigan [2]. The aim of this project was to preserve the massive collections of these research libraries and to allow anyone on the internet to access them for free. This sparked interest in automatic scanning and the development of commercial products.

Several patented configurations for book scanners are currently in use and are categorized by page turning method. The first design holds a book face-up while a swinging arm uses vacuum suction to turn the pages and an overhead camera captures images [3]. A second design holds a book face-up in a V-shaped cradle while two digital cameras capture images. To turn pages, a flat piece of plastic is inserted between pages and turns them as it rotates [4]. Another method involves blowing air to “fluff” the pages apart, and a vacuum is raised off the surface of the book to turn pages [5]. The majority of these methods are fast but not especially reliable, with error rates around 5%. Commercially available scanners that incorporate those methods are also extremely expensive. With prices ranging from $50,000-250,000, they are essentially inaccessible to smaller libraries [6-8]. Some of the scanners with lower cost such as BookDrive still require manual page turning, and are far less efficient than a fully automated scanner.

Since commercially available devices are either too costly, not reliable or not efficient, the goal of Google’s project has been to manufacture an affordable, reliable book

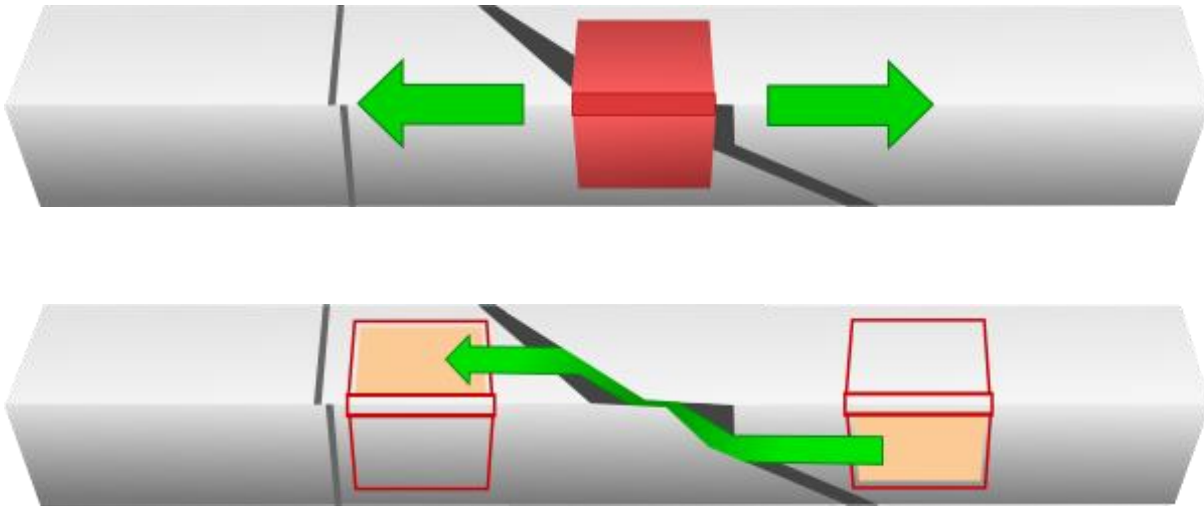

**Figure 1a** (top): “A book moves back and forth over the machine” [9].
**Figure 1b** (bottom): “Each time across, a vacuum sucks a page from one side to the other” [9].

scanner that is fully automated. This project is also intended to be open source, so that any library can have access to the engineering drawings and manufacture a scanner for their facility. Dany Qumsiyeh produced the first prototype while he was an employee at Google in 2012. He also built a second prototype that included improvements from the first before handing the project to a University of Michigan senior design team in 2013.

The most recent (third generation) prototype consists of a moving “saddle” seated on an inverted V-shaped base that forms the body of the scanner. A channel is cut through the top of the body to allow pages to fall through it. A user places a book face-down in the saddle and a motor moves the saddle down the body of the machine, scans the two exposed pages, then a vacuum “grabs” the page currently facing down and pulls it into the channel. As the saddle moves back towards its starting position, the page in the channel is funneled into a separate channel and exits the body on the opposite side, effectively turning the page (Fig. 1 a-b, above). This existing prototype of the linear book scanner is functional, but changes need to be made so that the scanner is as reliable and cost-effective as possible.

**METHODS**

To develop the next generation of linear book scanner, the first step was to fully define the problem by investigating current scanning products and interviewing the librarians in charge of digitizing the UM library. Next, concepts for the new prototype were generated and compared to select the most promising design. Finally, engineering analysis was performed to verify that the selected designs would function as intended. This phase was also used to further refine many of the physical design features.

**Stakeholder Needs and Specifications**

An investigation of user needs was conducted through interviews of the library sponsors and a tour of current book-imaging facilities. While the University has already imaged 90% of its books, it quickly became clear that current imaging methods were inefficient. While the library has several systems in use, none can consistently turn pages without human intervention, regardless of price. The most reliable system in use is the Zuetschel, which has no automatic page turning ability at all and requires a person to turn every page by hand. The library also has a Treventus which can scan very quickly, but the error rate for skipped pages is still around 5% for this $100,000 system. After speaking with the employees in charge of scanning, the user requirements for a new scanning system were defined.

First, the device must turn pages reliably. This means that it should minimize the rate of skipped, duplicated and damaged pages to below 10%. While 10% is still a relatively high error rate for a book with hundreds of pages, this number is comparable to the error rate of the Treventus and is a reasonable place to start. Low cost is the second most important requirement for the book scanner, since the purpose of the open source product is to increase accessibility. This means that the design should be both simple and cheap enough for a smaller library to build. Specifically, the goal for the project is for the material costs to be below $1000, as specified by the sponsor. In addition to reliability, it is preferred that the scanning process require as few manual adjustments as possible. Ideally, several scanners could be running at once with one technician working to supervise all the machines. Additionally, the scanner should be able to accommodate a large range of book sizes. The intended range should include all common book sizes, with the smallest having dimensions 4”x6” and the largest 12”x12” [10][11]. Any restrictions on the physical design are simply a matter of practicality - the scanner must be able to fit on a table top (2’x4’) and two people should be able to move it. Each of these requirements is summarized in following table.

Table 1: User specifications numbered by priority

| | |
|---|---|
| **#1 Must turn pages** | • Does not damage book<br>• Includes sensors to detect jams<br>• Turns one page at a time |
| **#2 Inexpensive** | • Less than $1000 to manufacture |
| **#3 Minimal human intervention** | • Minimal setup tasks<br>• Fully automatic once book is setup |
| **#4 Works for a variety of books** | • Fits books 4-12" wide<br>• Suction adjusts 3-9" high<br>• Accommodates paperback & hardcover<br>• Bends pages ≤ 30° |
| **#5 Portable** | • Weights less than 50 lbs<br>• Footprint < 2 'x 4', height < 2' |
| **#6 Easy to use** | • Standard power source<br>• Less than 10 steps to begin operation<br>• User not required to program interface |

**Concept Generation and Selection**

After speaking to the library sponsors and fully defining their requirements for the book scanner, the next step was to begin generating design concepts. While it was clear that the sponsors intended for the new design to be similar to the previous prototypes, the first round of the concept generation process also included alternative page turning methods. It was important to begin by evaluating the page turning process as a whole so that even well-established ideas could be examined for quality. In this first round, ideas as diverse as electrostatics and purely mechanical page turning were evaluated against the original vacuum suction method. In the end however, a Pugh chart was created and it became clear that a pneumatic device was still the best option. Once the general shape of the scanner was chosen, a functional decomposition was created to outline each subsystem of the scanner, and an additional set of concepts were generated to address each one. These new concepts focused on making improvements over the previous prototypes. After each idea had been fully developed and presented to the team, a discussion was held to decide which of the new ideas should be included in the final design. Ultimately, it became clear that the major new innovation would be to add sensors to detect which pages had been turned, rather than adding new fans or hardware and change the geometry of the page turning slit. While the previous prototype had incorporated a plastic “finger” to guide pages as they were being flipped, a new flap would be included in its place. This would allow pages to be turned in one fluid motion instead of two distinct steps. The idea was to prevent errors by removing the obstruction of the “finger” as pages moved through the body of the scanner.

The final concept was a simple combination of several design features, and stood out because it combined the best aspects of the old prototypes with new concepts that were intended to fix the flaws of the previous versions.

**Engineering Analysis**

With the concept selection process complete, engineering analysis was performed to nail down the specifics of the prototype design. Three primary design drivers were identified to be page turning, page separation and error detection.

Page Turning:

Page turning was of the highest priority since it represents the main function of the scanner and the area most in need of improvement. This called for the most detailed analysis, which included empirical testing to determine the width of the page turning slit, the material of the flap used to guide the turned page, and the configuration of the channel into which the turned page would slide as the book moves across the scanner. This was meant to determine the overall geometry of the page turning mechanism and was evaluated by testing books on a sketch model. In each trial, one aspect of the model was changed, and the effect on the turned pages was noted. After several iterations, each feature of the design could be optimized. From this it was decided that the material of the page guiding flap inside the scanner should be made to have the lowest friction possible, the top of the page turning slit should have a gradual curve (Fig. 2) and the slit width should be left variable to allow for some design flexibility after manufacturing.

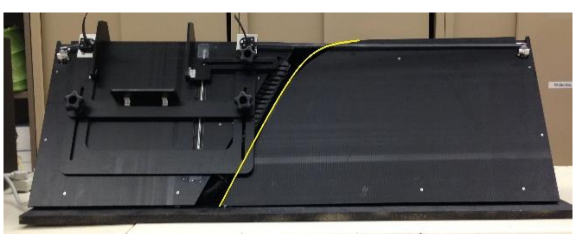

Figure 2: Outline of curved page turning slit

Page Separation:

The second most critical design driver for the book scanner was that it must separate one page from the rest without skipping or duplicating pages. Since the primary mechanism to separate pages was vacuum suction, theoretical calculations were done to estimate the force needed to separate pages. By estimating the area of contact between the vacuum tube and page, a force applied by the vacuum was calculated assuming a contact area of one square inch and a pressure of 20kPa. This was then compared to the weight of a piece of paper, and it was found that the force exerted by a typical vacuum was about 100 times higher than was needed. It was concluded that there should be more than enough power on a standard vacuum to allow the book scanner to function, and that creating a pressure release valve could be a useful design feature, rather than working to find a higher-powered vacuum.

Frictional forces during the scanning process were also of significant concern since book pages directly contact and slide along the body of the scanner. To quantify this, the frictional force required to drag various books across the previous prototypes were measured, and the distribution of forces on the book were calculated. This created a more complete model of the friction on the final prototype, as it corrected for the change in material, variation in books and a varied apex angle.

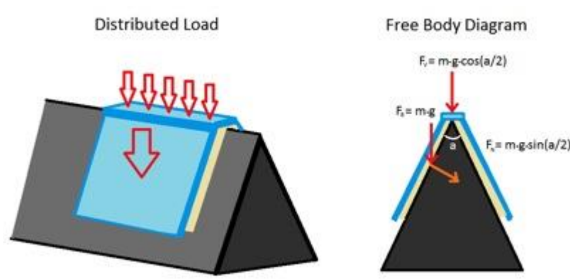


Figure 3: Free body diagram representing loads of book on scanner body

From this analysis, it was found that a slippery plastic has lower friction against book pages than aluminum, and that a steeper apex angle would place the majority of frictional forces on the tougher spine of the book rather than on the pages themselves. Because of this, the apex angle was chosen to be 60° instead of 90°.

To choose a final plastic material for the scanner body, the CES material database was consulted. It was found that Delrin rather than acrylic would be both be more environmentally friendly and cost effective. Delrin was used in the final prototype, with vinyl for the inner flap.

Error Detection:

Finally, the third primary design driver is error detection. The concept selection process supported adding sensors to the prototype instead of additional hardware, and several of these were selected and tested. To detect if the scanner had failed to turn a page in one cycle, the use of a proximity sensor was proposed. When operating properly, the sensor should send a signal when a page has entered the page turning slit, but the operating parameters of the sensor would have to be tuned. To verify that this was plausible and that the right type of sensor had been selected for the job, the output signal from a spare proximity sensor was measured. Various obstructions were placed in front of the sensor, and its output was recorded. It was found that a proximity sensor has no problem detecting objects made of paper, and that the distance between the sensor and a page on the prototype would be within the operating range of the sensor.

To address the more difficult problem of detecting whether multiple pages had been turned, a capacitive sensor was proposed. It was hypothesized that the voltage between a pair of parallel plates would change significantly when a piece of paper entered the space between them. This change in voltage could be measured as a signal to detect not only the presence of a page in the page turning slit, but also the number of pages. Since this sensor would have to be fabricated entirely by hand, a feasibility check was needed before proceeding with the design process. To do this, two plates were constructed and connected to a standard LCR meter. Using the capacitance measurement setting, the two plates were held loosely against the two sides of various numbers of pages. After three trials for each of one, two, and three pages for two different books, I found that the capacitance measurement was on the order of hundreds of picofarads and was roughly proportional to the number of pages. These values varied depending on the page thickness. We concluded that with a high enough resolution measurement, we could detect the number of pages between two plates.

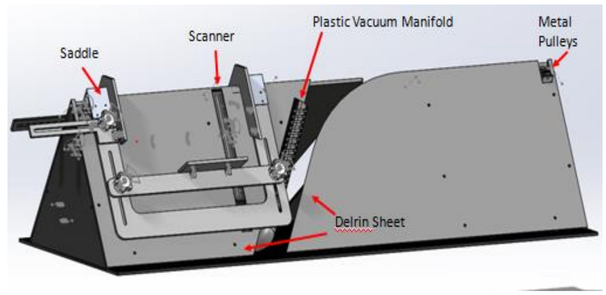


Figure 4: CAD screenshot of our prototype

**RESULTS**

**Final Design and Prototype**

The final design for our prototype can be seen in Figure 4, above. It consists of two major assemblies: the saddle and the body. The body is constructed of low-friction Delrin plastic, which is fastened to a particle board base with custom-made, steel brackets. It has an apex angle of 60-degrees, a parameter which we determined in our preliminary testing to cause less stress on the binding of the books than larger angles. One side of the body has the page intake channel, in which a vacuum tube is mounted tangent to the body panel. It features an attachment which adjusts the height at which the suction is applied. Within the body, a vinyl flap directs the page from the intake channel to the outtake channel. It is glued flush to the chamfered edges of the body panels using epoxy. All edges and surfaces have been sanded smooth to prevent any damages to the book pages.

All electronic components of the prototype are packaged within the body. Near the intake end of the body, the motor is mounted to the body panel. It transmits power to the saddle using a timing belt and pulleys which are recessed into the body panels at each end of the machine. These pulley assemblies each include a limit switch to detect the end of the saddle's travel. Additional error detection is accomplished using an IR (infrared) sensor which is mounted to the inside of the body panel across from the intake channel. This sensor reliably detects whether or not one or more pages have entered the channel. These sensors are controlled by an Arduino and a custom circuit board. Finally, the body contains a vacuum, 5V power supply, and power strip.

The saddle both contains and controls the movement of the book being scanned. All surfaces resting on the body are made of Delrin plastic to minimize friction. The rest of the assembly is held together by aluminum 90-degree brackets and steel 60-degree brackets. It has six adjustment knobs which move a lateral slide to contain the book's binding and two vertical slides to hold the book's covers. These vertical slides are covered with a squishy, high-friction material to keep the covers and binding from moving during the scanning process and to hold the weight of the book off of the pages.

Our linear book scanner prototype has made some significant design improvements from the three previous prototypes. First, it has a lower apex angle and a lower height overall. It has a simplified saddle adjustment system as well. We have also successfully packaged all electronic components in the body and tied all together using a single external power cord. Most importantly, its updated page-turning method is far more gradual and much less damaging to books than previous prototypes. Figure 5 below, shows an isometric view of our manufactured prototype.

Figure 5: Isometric view of our prototype

**Validation**

In order to validate our prototype, we performed numerous experiments during which we evaluated certain specifications of the machine for ten-cycle intervals. First we evaluated page turning speed and page turning accuracy. For each of these specifications, we conducted nine trials. We tested three different books at three different places in each book (beginning, middle, and end). For page turning speed, we recorded the number of cycles (pages turned) in the three minute interval and extrapolated to estimate the number of pages turned per hour. Our goal speed was 60 pages per hour based on competitive products. For page turning accuracy, we recorded the number of errors and the number of corrected errors in the three minute interval. An error was defined as a skipped, duplicated, or damaged page. If the IR sensor detected a skipped page and the scanner correctly turned the page on the correction cycle, we recorded a corrected error. Our target error rate was less than or equal to 5% (similar to the commercial Treventus scanner). Our final trial runs aimed to quantify the need for user adjustment to the scanner. For these trials, we recorded the number of times a person had to make any adjustment to the book or scanner during a period of ten cycles. This number would be extrapolated to estimate the number of adjustments per hour and number of adjustments per 100 pages. Our target value was five adjustments per 100 pages or less. The results of these tests can be seen in Table 2, below. For the mid-sized hardcover book, we found that page turning was highly successful.

Table 2: Validation testing success rates

| | | First Third | | Middle Third | | Last Third | |
|---|---|---|---|---|---|---|---|
| **Book Description** | Speed (pgs/hr) | Success Entering Channel | Success Exiting Channel | Success Entering Channel | Success Exiting Channel | Success Entering Channel | Success Exiting Channel |
| 5.5 x 8.5", hardcover, medium page thickness, 0.79 lbs | 168 | 90% | 90% | 70% | 100% | 60% | 80% |
| 6 x 9.5", hardcover, medium stiff pages, 1.83 lbs | 168 | 80% | 10% | 70% | 10% | 70% | 0% |
| 6 x 9", paperback, thin pages, 0.98 lbs | 168 | 0% | 60% | 0% | 70% | 0% | 60% |

After our active trials, we evaluated the specifications of cost, weight, and size of the prototype. We set a goal to spend less than $1000 on our prototype. We also noted any cost-saving measures and estimated the amount of time it would take to replicate our entire prototype. Our prototype weight and size were measured using a standard scale and tape measure in the lab. We aimed to have a total footprint of 2’ by 4’ or less and a total weight of less than 50 pounds.

## DISCUSSION

### Design Critique

The primary user requirement for the device was to be able to consistently turn individual pages of books. The book scanner was moderately successful in turning pages one at a time for small books, which were initially used to test the scanner’s functionality, which resulted in an accuracy of 85%. While this is slightly lower than the specified 90% accuracy, it is close, and the scanner could likely achieve this level of accuracy with more adjustments to the flap used to separate the pages at the inlet of the slit. The scanner was able to scan 168 pages per hour, which was more than twice the specification of 60 pages per hour.

The scanner is also orders of magnitude cheaper than its main competitors, so it meets the requirement of low cost. The scanner is also only 1% of the cost of comparable scanners that turn pages autonomously, costing only $950, which is less than the specified cost of $1000. The majority of the cost was also just the Delrin used to construct the structure, so the cost could be further decreased by using a cheaper material or less Delrin.

The requirement for minimal human intervention was achieved successfully through automatic error detection. The infrared proximity sensor successfully detected every time the book failed to turn a page, and it triggered the scanner to reverse and scan the page again. This successful detection and reversing minimized the need for users to manually reset a jammed page. While the scanner could not detect multiple pages, the addition of a thin flap at the inlet to the scanner greatly reduced the number of pages that would enter the scanner, making the infrared sensor sufficient to detect most errors. While the requirement was satisfied, it could be further improved by adding a sensor to detect multiple pages, so it would be preferable for such a sensor to be included in future versions of this device.

The book scanner was not able to meet the user requirement to work for a wide range of book sizes. While the device was designed to accommodate books between 3 and 9 inches wide, it was not designed to be able to handle the wide range of book weights. The vacuum was adjustable to work throughout the specified range of 3”-9”, making the design able to accommodate the planned dimensions of books. Light books worked very well in the scanner, but heavier books put too much force on the scanner to allow pages to exit from the slit, causing pages to jam and tear. This means that the specification for the scanner to turn the pages of most common book sizes was not met. Future work to improve the flexibility of the device to turn a variety of page sizes should focus on making the slit outlet more gradual. The scanner successfully met its portability requirement. The scanner weighed 47 pounds, which is less than the specified maximum weight of 50 pounds. The scanner also had a footprint of the specified maximum of 2’x4’. This is a major improvement over past years, because the scanner had a smaller overall footprint, was not as tall, and contained all parts inside the device. Past iterations relied on a bulky, external vacuum, which greatly increased the effective size of the device, even though it was not counted in the size of the device.

The scanner also met the requirement of being easy to operate. The setup required only five steps, which is less than the specified ten steps. The device only needed to be plugged in to be turned on, and then a single switch started and stopped the scanner from turning pages. The scanner was also considerably easier to plug in than earlier versions of the scanner. Rather than rely on separate wall plugs for the motor, vacuum, and controller, all of the power cables were connected internally, and there was only one power cord for the entire device,

which made the device simpler and more aesthetically pleasing.
Overall, the device successfully met the user requirements for light books, but it lacked the desired range and robustness of operation.

Challenges and Successes:

There were several components on the device that did not perform as well as expected, the worst of which was the capacitive sensor. In order to detect the number of pages and detect if too many pages were turned, a capacitive sensor was added to the scanner. Initial testing using the plates of an LRC sensor revealed that a capacitive sensor could be used to detect the number of pages passing between two plates. However, the plates that were used in the device were not as precisely manufactured as the ones used for initial testing, which decreased the accuracy of the sensor. More importantly, the LRC sensor was too large to fit inside the scanner, so the Ardunino microcontroller was used to detect the capacitance between the two sensor plates. The Arduino is not able to determine capacitances as accurately as a LRC sensor, which resulted in a signal-to-noise ratio that was too low to determine the number of pages passing through the scanner. To fix this issue, a dedicated capacitive sensor should be added.
The center flap used to turn pages also did not perform as well as expected. The inlet of the slit is the most critical part of the page separation process, so most of the design efforts were focused on improving that part of the flap. As a result, the pages turned very well through the beginning and middle of the flap. However, the outlet of the pages did not prove problematic in previous versions of the device or in preliminary testing, so this part of the device was largely ignored in design. In order to reliably attach the flap to the wall of the scanner, the flap was glued at a fixed angle, with respect to the plane of the book on the outlet side of the scanner. This angle proved to be too sharp for heavy books, and the pages would jam and tear, rather than slide back in line with the rest of the pages. To fix this, the outlet flap should have been mounted with a gradual curve into the plane of the book, but this was difficult to achieve with the glue that was used, and any attempt to change the flap once it was attached would likely have destroyed the device. For future versions of the device, the flap should be designed to be curved on the outlet slide as well as the inlet side, to allow the pages to slowly turn from the slit into the rest of the book.

Fortunately, several features of the device also performed better than expected, such as the infrared sensor. When the sensor was installed and calibrated, it detected whether or not a page was there, every single time, without further configuration. It was expected that some further calibration would be needed to distinguish the pages of different books from the background of the scanner, but all books that were tested were easily distinguishable from the plastic behind them.

The thin edge that was added to the inlet of the scanner also helped considerably in separating pages to ensure that only one page was turned at a time. While three or four pages would typically enter the scanner before adding the extra edge to the inlet, only one page or occasionally two would enter the slit with the addition of the thin edge on the inlet. The edge was simply two pieces of tape pressed together along the edge, which narrowed the width of the slit at the inlet and making it thinner. The thinner edge prevented the pages from separating along the blunt edge of the inlet, which caused some of the pages to enter the slit before adding the extra edge.

A final improvement that worked considerably better than originally expected was the power strip inside the device. Initially, the vacuum, Arduino, and motor power supply power cables were all designed to come out separately from the scanner, which would have added unnecessary clutter for the users. By combining all of the devices into a single power strip, the scanner was able to house all components internally, which reduced the amount of wiring that was needed. The simpler cable setup also made the whole device much easier to understand and use, as well as making it much easier to pick up and move, because the users only need to keep track of a single cable extending from the device.

**Future Work**

The most important piece of future work on the scanner will be to fully integrate the scanning elements into the device. While the scanning bars are installed in the scanner, they are not connected to a computer, and, as such, they cannot output any useable scanned images of books. While there is code and plans for the electronics from previous years, this subsystem would have to be integrated with the output signals from the Arduino, which tell the scanners to begin scanning. Once the scanner controller is integrated into the device, it will be able to produce useable scans of books.

Another module that should be added to the device is a dedicated capacitive sensor. This sensor could consist simply of a resistor and a voltmeter connected across the two capacitive plates, but the voltmeter would need to be more accurate than the one built into the Arduino. The voltmeter will need to be calibrated to detect the expected voltage drop across the capacitve plates for one or two pages, giving the sensor enough of a signal-to-noise ratio to distinguish the pages, without outputting more precision than can be registered by the 8 bit analog pins of the Arduino. An alternative approach would be to use a high precision capacitive sensor, but this system would be very large and expensive, requiring a significant increase in both the budget and the volume of the scanner.

A final change would be to redesign the flap outlet. While this would constitute a significant design change, likely requiring a new rear half of the device, it is critical to allowing the device to scan the required range of book sizes. The new outlet should curve very slowly from turning the page across the slit to aligning the page with the rest of the book on the outlet side. Currently, the transition is almost instantaneous, and the friction of a heavy book is too much for the page to overcome, leading the page to jam and tear. If the turning page were almost parallel to the rest of the book when the two pages touched, as is the case with a more curved flap at the outlet, then the page would not jam due to friction, and the scanner would work equally well for heavy books and light ones. This curve could be achieved by filing down a substantial portion of the outlet edge of the scanner and gluing the flap to this gentler curve. Because it is difficult for epoxy to adhere to Delrin, the attachment would be more challenging, and it would likely fail, the resulting outlet geometry would be worth the additional effort.

Broader Implications:

Upon the completion of the project, the book scanner prototype and all associated documents were provided to the University of Michigan's libraries. While the device is still not yet useable as a full book scanner, with a bit more work, the libraries will be able to use this prototype to scan books, as a part of the Michigan Digitization Project, which is working to produce digital copies of the university's entire book collection. While this scanner has a higher risk of damaging books than the university's current book scanners, it is still a useful resource for scanning replaceable books, accelerating the digitization process.

As an open source project, all plans for this linear book scanner will be openly available online for public use. With the more reliable and less damaging design of this version of the book scanner and the scanner code and electronics for the previous iteration of the project, local libraries and enthusiasts around the world will be able to develop their own versions of this scanner to scan digital versions of their books, increasing the availability of digital books in all regions and languages.

This greater availability of digital books will allow easier access to the vast wealth of knowledge stored in the world's books as the digitized copies are uploaded to the internet. Easier access is both a blessing and a curse. While individuals will benefit from information that was never available to them before, they will also be able to easily pirate books that they could have accessed at a price from book vendors. As books become available online through more libraries and individuals, piracy of books will become increasingly more prevalent, hurting authors, publishers, and vendors. As with music, the digital age is making books easier to access, but the cost is increasingly falling upon the producers, rather than the customers.

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**AUTHORS**

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Garrett Cullen grew up in Ada, Michigan, before going to the University of Michigan. Garrett is pursuing bachelors and masters degrees in mechanical engineering along with a physics minor, multidisciplinary design minor, and an international minor for engineers. Garrett is a member of the Engineering Global Leadership Honors Program, and he does structural engineering research for the Michigan eXploration Lab, which focuses on the development of satellites. Garrett works with the structures team to design and manufacture the structural subsystems for the satellites, and he develops devices to test the satellites. In his free time, Garrett enjoys running. He is an active participant of the Michigan Running Club, where he has been a board member for the past two years. Garrett's races competitively in both cross country and track, and his favorite events are the four by 800 meter relay, the 5000-meter run, and the 3000-meter steeplechase, in which he is the 2014 NIRCA national champion. Garrett enjoys building things outside of coursework and research. He is currently developing a mobile beverage distribution device for home use, which will preserve cold, kegged beverages, pour them automatically, as well as being able to move autonomously. The device will greatly simplify the process of acquiring beverages, leaving more time to enjoy them.

Kelsey Lindberg is a senior at the University of Michigan, where she will be graduating in May 2014 with a Bachelor's Degree in Mechanical Engineering and an International Studies Minor. She is involved in Phi Sigma Rho, an engineering sorority, where she has held positions as a PULSE (Peers Utilizing Leadership Skills for Education) Representative and Philanthropy Chair. She is also involved in KGrams, a student-run penpal organization, as well as professional organizations such as WISE (Women in Science & Engineering), and SWE (Society of Women Engineers). In WISE, she has held positions as student mentor to three incoming freshmen in the STEM program, and a tour guide to promote WISE. Within SWE, she has held "elite member" status and will continue to stay involved post-graduation. Aside from academic programs, her extracurricular activities also involve Intramural sports including sand volleyball, wallyball and indoor volleyball. When she is not playing volleyball, she enjoys running half marathons and hopes to participate in a full in the upcoming year. Her future plans include working as a Product Development Engineer at Ford Motor Company in Dearborn, Michigan, where she will be starting in June of 2014 as an FCG (Ford College Graduate).

Lauren Staszel is a senior in Mechanical

Engineering and the Multidisciplinary Design Program. She is very involved with the Michigan Hybrid Racing Team, where she is the current Business Division Leader. In previous years she has held the position of Rules and Safety Officer and focused on the design, testing, and fabrication of the high voltage system. She is also a member of Phi Sigma Rho sorority for women in engineering and the technical sciences where she has held the position of new member educator. Lauren studied international project management in Troyes, France in the summer of 2011 and has since aspired to travel as much as possible after graduation. Her future plans also include interning as a Project Engineer at 3M in Maplewood, MN this summer and finding a permanent position after she graduates in December of 2014.

Teresa Tombelli

Teresa Tombelli is a senior in Engineering Physics who will be graduating in May 2014. While she has taken numerous classes in physics, the core of her studies focus on mechanical engineering, and she has become increasingly interested in design. In addition to the current book scanner project, Teresa has been involved in numerous design projects including a sustainable insulation project in Guatemala through BLUElab, a battery charging cell phone case for a product development class and research in both Mechanical Engineering and the College of Pharmacy. She has found all of these projects exciting and rewarding, and they have prompted her to pursue further education in mechanical engineering after she leaves Michigan. Next fall, Teresa will be attending Stanford University for her Masters of Science in Mechanical Engineering. She hopes to further her studies in mechanical product design and mechatronics at Stanford's well-known Design School and to find a career in research and development. Outside of class, Teresa enjoys trying new recipes, sampling food from around the world and has been to most of the restaurants in Ann Arbor.

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