# Making PiNAOqio Read: Turning the Pages of a Physical Book

Nathan Warner (njw13)
*Imperial College London*

**Abstract: In this report I outline the challenges associated with enabling PiNAOqio to read from and turn the pages of real books. Several existing devices that accomplish similar functions will be discussed followed by an in depth overview of our proposed servo actuated mechanism. The progress thus far in its implementation will also be shown.**

## I. INTRODUCTION

Currently on the market there exist a number of story telling robots [1]; each of these however relies on the use of tablets loaded with e-books. It has been shown that prolonged use of tablets can have a detrimental impact on young children [2,3]. In addition, if children are introduced to literature in a purely digital format it may deter them from reading physical books later in life. Heretofore, the concept of an interactive robot story teller that can read physical books is a niche that has not been explored.

One of the toughest challenges in realizing the PiNAOqio storyteller robot is his ability to turn the pages of real books. This proves difficult to achieve reliably since the operation requires many degrees of freedom each with accurate synchronization. In addition, there is the variability imposed by the dimensions of different books. After researching existing page turning systems, we devised a bespoke mechanism that utilizes an arrangement of servos configured as a state machine and controlled by the Raspberry Pi.

## II. REQUIREMENTS

The page flipper mechanism will be responsible for turning the pages of the loaded volume so that there is a seamless transition in the flow of the passage. In order to accomplish this goal, the system will need the following features. Firstly, the operation must be reliable; this means there should be minimal glitches, such as turning more than one page at once or failure to complete a page turn. Due to time constraints and complexity, it is expected that the system will fail occasionally and may need human intervention. However, with good design these instances should be made as rare as possible so as not to adversely affect the experiment. The next important feature is that the mechanism should not crease the pages. This is clearly undesirable for the owner of the book if it damaged by the reading process. Furthermore, the performance of he OCR algorithm is drastically reduced if the pages have any irregularities.

The total time to complete a page turn is another important consideration. In order to avoid dead-time, PiNAOqio can commence a page turn prior to reaching the end of a page. However, if the mechanism takes more than several seconds to complete a flip it may prove to be a distraction and may influence the results of out experiment, seeing as one of our dependent variable is information retention. At the same time, the pages should be turned in a manner that retains a humanoid characteristic; ideally not too fast, at a speed comparable to that of a human reader. Finally, the product should be safe and well suited for its intended use around small children.

## III. RELATED WORK

Through our research we uncovered several existing mechanical solutions for turning the pages of physical books. Although nothing we found was directly comparable to our application and requirements, the following products contained aspects that had an influence on our final design.

Most notably the linear book scanner [4], a project that was initially started by google as a means of archiving physical books, but has since been adopted and developed further by several research groups [5]. The design consists of a prism shaped assembly upon which a face down book slides back and forth. Each time the book makes a pass a vacuum sucks a page from one side to the other. The book also passes over a scanner that digitizes both pages. This approach is optimized for scanning a large number of pages per hour with small error. It does not, however, retain any of the familiar human aspects of reading and requires a rather bulky assembly, therefore rendering it far from ideal for our project.

An accomplished commercial solution, the Treventus ScanRobot 2.0 MDS [6], can be purchased for $250,000 and is capable of scanning 2,500 pages per hour. The device has a scanning head that moves into the gutter of the book. Once there it applies a vacuum to suck up the page, as it moves up it scans the page, then once at the page edge the machine applies a blast of air to ensure the page falls to the correct side. This is a highly efficient and effective approach, although it isn't suited to paperbacks as these do not sit open like hardbacks. There is also a high level of complexity involved; with an air blaster, vacuum pump and various stepper motors needed for its operation.

Another related project was undertaken by a team at the University of Ohio [7]. Their application was to assist sufferers of cerebral palsy in the turning of bound pages. The device that they developed consisted of a rubber wheel used to lift the page. Once lifted a turning arm would then push the page onto the opposite side. This approach was very simplistic requiring minimal external components. The shortfall is that the design only works with large textbooks style books, where the pages naturally fall to either side.

## IV. IMPLEMENTATION

As shown by our research, there are a number of methodologies that we could deploy to accomplish the page flipping task. The three main ones we considered were based on either suction, pneumatics, servos and stepper motors, or a combination of these. We also divided the page flipping task itself into three sections and considered different methods for each: lifting the page, turning the page and holding down the page.

To generate the initial force to lift the page we could use a small vacuum pump to generate the suction. This approach is good in that it will be unlikely to crease the page. Although, if the interface with the page does not make good contact the vacuum may fail to lift the page; hence the reliability may not be great. This would also entail a high level of complexity with a number of custom 3d printed parts required.

Instead for the page lift section we decided to use a small rubber wheel, in the same way as the team at University of Ohio [7], that would make contact with the page and turn a small amount to raise the page. This wheel could be mounted on a servo arm to position it on the page then move it out of the way for the flip. Initial testing with such a wheel revealed this method to be rather effective, whilst also much simpler to implement. The rotation can be achieved either using a stepper motor or a continuous rotation servo.

Once lifted the page could be flipped using a blast of pressurized air similar to the ScanRobot 2.0 MDS. We decided against this; both because of the requirement for additional hardware, and since it will only prove effective on hardbacks or books with heavy pages. The implementation we decided to go with uses a flicker servo to catch the raised page and push it to the adjacent side. Since the page will not fall neatly on its own, a "digger arm" with two degrees of freedom will catch the page and assist it down. This should be more reliable as the page is guided through the entire path of travel. It also uses cheap and easy to control servos.

The final stage, holding the pages, would not be needed were we using textbooks or hardback books. The pages of paperback books on the other hand do not tend to fall open naturally, therefore needing assistance to be held flat. This also helps improve the accuracy of the OCR. The easiest way to achieve this would be to use holder servos on either side. These would be able both to push down to hold move up to release/accommodate a new page.

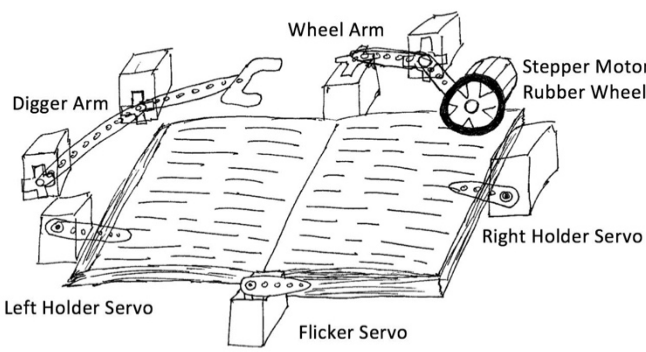


*Figure 1: Page turning mechanism overview*

## V. ASSEMBLY

For the construction of the system we decided to use 5mm/3mm acrylic wherever possible and 3D printed PLA for more complex parts, such as the wheel mount. Acrylic was chosen because it is safe and easily cut using a laser cutter. The laser cutter also allows us to round any sharp corners that may be a hazard around small children. Acrylic is also more aesthetically appealing than other cheaper alternatives such as plywood; an important factor when the target audience is children and user enjoyment is critical to our hypothesis.

The servo we chose was the "Modelcraft RS 2 JR BMS-410C", a plastic gear standard analogue servo. This model was chosen chiefly due to it's cheap price, which was important seeing as we needed a large number, and also for its more than adequate torque of 35Ncm. Each servo is supplied with an arm containing mounting holes allowing for custom 3d printed/ laser cut parts to be attached.

Due to the large number of servos involved in the design it would be desirable to have a convenient way to mount them. The following servo brackets, shown in figure 2, were designed using laser cut acrylic that serve as a universal approach to mounting all the servos. These brackets neatly slot into pre-cut holes in the base avoiding the need for glue or bolts to hold it in place. Additionally, multiple holes can easily be cut at various different angles and locations. This enables us to quickly and easily tweak the positon of each servo for optimal performance. For instance, the angle at which the rubber wheel is positioned on the page or the distance of the digger arm from the book can be varied. This design greatly simplifies the the development process and makes prototyping much faster.

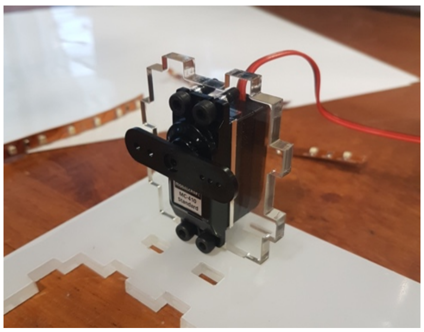

*Figure 2: Universal Servo Bracket*

One issue that proved problematic in our design is that the heights of the front and rear covers can vary quite significantly as the pages are turned from beginning to end. To compensate for this, we decided to place each cover of the book on an independent platform. We considered using stepper motors to alter the level of each platform as the story progresses, however this would add a large amount of complexity to the design. Instead we chose to position each platform on a set of springs. This has the effect of lowering the heavier side with more pages, hence reducing the height disparity between the two sides.

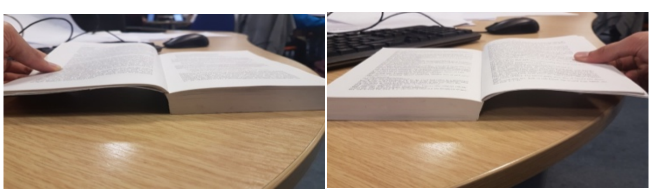

*Figure 3a: Height difference of front and rear covers*

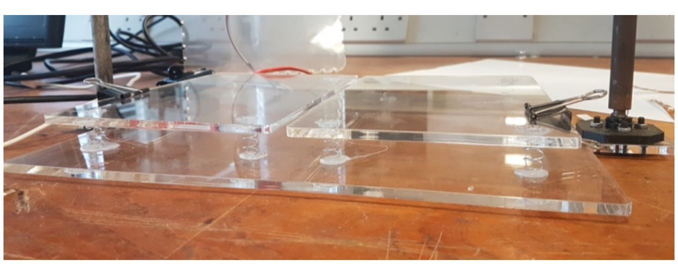

*Figure 3b: Independent Spring Platforms*

We constructed a preliminary setup as shown in figure 4. The purpose of this prototype was to determine the appropriate height at which to place the camera in order to achieve accurate OCR; this would then dictate the overall dimensions of the final revision. In order to conveniently vary the height of the camera, metal rods were attached to the base using 3d printed supports. Two smaller metal rods were then clamped to these, serving as a rail upon which the camera and pi assembly could slide along. The sliding was needed to assess whether OCR could be performed on both pages at once or if the camera would need to slide over each page individually.

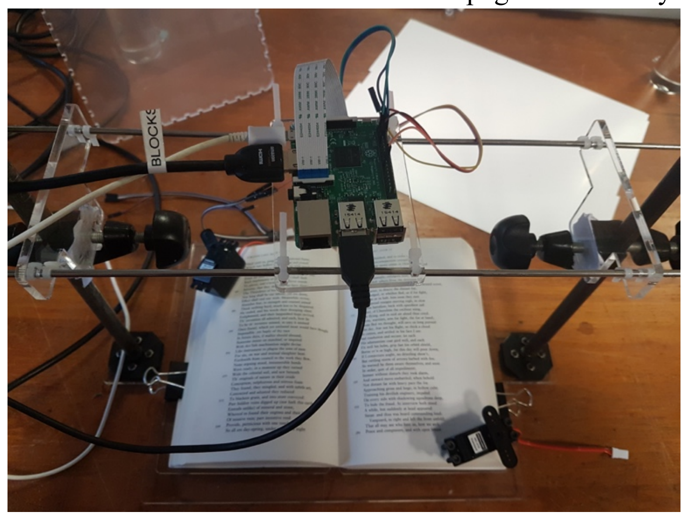

*Figure 4: Initial Test Setup*

## VII. SOFTWARE

The sequence of operation for each component of the system is illustrated in figure 5 and can be modelled as a state machine. Each servo is controlled via a PWM signal of 50Hz from a single GPIO pin, the duty cycle of this signal determines the position of the servo arm. For our selected servo model, a duty between 3.6 and 10.6% maps through an angle of 0 to 180˚.

The page turning event will be triggered once PiNAOqio is reading the final section of the second page. This could be initiated as the final block of text of sent to the NAOqi with a delay introduced if necessary.

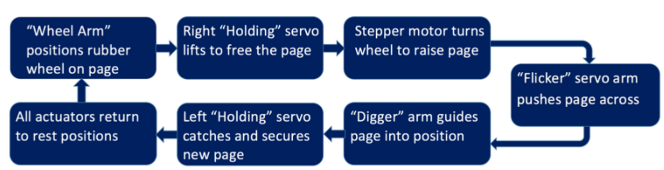


*Figure 5: Sequence of operation*

## IX. CONCLUSION

PiNAOqio is treading on uncharted territory with its ability to read hard copy books. Although a final prototype is yet to be completed, through the construction of a preliminary test setup we discovered the OCR to be effective form a single viewpoint of both pages. This was the main factor upon which the success of the project was contingent. We intend to start finalizing the design in the imminent future and are confident about its potential to effectively realize our hypothesis.

## X. REFERENCES


1) K. Smith, P. Jaqueline. "Storytelling Companion - Personal Robots Group". Personal Robots Group MIT, 2016. [Accessed: 14- Nov- 2016].

2) M. Dredge, T. Stuart. "Children's Reading Shrinking Due To Apps, Games And Youtube". *The Guardian*, 2013. [Accessed: 14- Nov- 2016].

3) Rowan, Cris. "The Impact Of Technology On The Developing Child". The Huffington Post, 2016. [Accessed: 14- Nov- 2016].

4) "Linear Book Scanner - The open-source automatic book scanner", *Linearbookscanner.org*, 2016. [Online]. Available: https://linearbookscanner.org. [Accessed: 17- Nov- 2016].

5) J.Y. Lim, R. Snyder, “Linear Book Scanner”, Team 23, University of Michigan, Michigan, 2013. [Accessed: 17- Nov- 2016].

6) "Book scanner ScanRobot® 2.0 MDS - The automatic page turner solution", *Treventus.com*, 2016. [Online]. Available: http://www.treventus.com/automatic-book-scanner-scanrobot.html. [Accessed: 17- Nov- 2016].

7) P. Charlton, F. Johnson. "Mechanical System For Lifting And Turning Bound Pages". University of Ohio, 2015: [Accessed: 17- Nov- 2016].

8) T. Shinbrot, "Page flipper for book copying", US4663873, 2016.

9) E. Shemoul, "Page turner", US5373772, 1994.

10) A. Tillinghast, "Automated page turner", 20050230592, 2005.