Forma.

Form-filling for the Blind
and Visually Impaired

Forma: Form-filling for the blind

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I. Executive Summary

Forma is a project that aims to make it easier, faster, more independent, and more private for blind and visually impaired persons to fill paper forms. These forms can represent much more than a piece of paper, and can be key to unlocking opportunities. Opportunities from which nobody should be left behind. Over the past year, we have spoken with stakeholders, and designed and iterated upon a solution which we believe does fulfill the intended goals, even as a first prototype.

Our solution has two parts: 1. the Forma web interface and 2. the Forma smart clipboard. Our technical and business models are as follows. We lease out the smart clipboard to institutions, like banks, or hospitals. Then an administrator from the institution can upload and process their forms, once-off, through our web interface. The smart clipboard can be kept at the front desk, and given to a blind user on the spot when it's needed. The smart clipboard is able to track the user's pen tip, and provide audible guidance to fill the form.

With our first full prototype, we have shown that our technology and design has been able to meet its stated purposes, being able to last a full day on battery, and run smoothly enough to reduce the time taken to navigate and fill a paper form.

II. Overview of Project

Imagine you are at the bank, the doctor's office, or the library and are asked to fill out a form. Simple, right? Blind and visually impaired (B/VI) persons have only one choice when filling out a form in person - asking those around them for help. This is a huge loss of both privacy and independence, especially in medical settings where the person would have to verbally speak out all their private information. Even if the form is provided in advance, speaking with users, we have found that it can take up to 6 hours to fill out a paper form on their own when there are zero accessibility options provided, which is often the case. This is where Forma comes in. Forma is a form filling solution for the B/VI targeted towards medical office intake forms. The current solution includes 2 parts: 1. a web interface that allows front desk administrators of medical institutions to upload intake forms and easily tag the inputs of the form, and 2. a smart clipboard given to the B/VI user that is equipped with a camera to recognize the form inputs and the pen's location to guide the user through audio feedback.

With this, our goals for this project are to create a product that can aid a B/VI person to fill in paper forms with more ease, greater privacy, better independence, and less time. Of course the beneficiaries are the B/VI users, but the institutions stand to benefit too, as they can reduce check-in times for blind customers, reduce their costs for disability compliance, and can improve their customer satisfaction. When we think of form filling, it's not just simply manual data entry. That is merely the logistical side. Being able to fill forms is crucial to access opportunities like jobs, benefits, healthcare, and education, just to name a few, and this is something often overlooked in our daily lives. We believe that blind persons are entitled to the same opportunities as everyone else, and this is the overarching problem that we wanted to tackle. This is a solution that we believe is deeply needed, especially during the transition period between when forms are starting to become digitized from their paper formats. We believe that no user should be left behind.

III. Technical Description

There were various specifications, requirements, and constraints that we were working with for our project, many of which included societal and economic considerations. Since we are developing our project for an underserved population we needed our product to be affordable. Although the institutions will be the main buyers of our technology, we wanted to ensure that it would not be an extra burden so that blind or visually impaired individuals will have accessibility options for wherever they would need to fill out forms. As such, we set a goal for our smart clipboard to cost less than $100. We also needed to ensure that our product would be easy to use by both the B/VI user and the institution. It can take anywhere from 1-6 hours for B/VI individuals to fill out a paper form so we wanted our product to lower the time constraint to less than 1 hour. Additionally, since we could be dealing with personal information, such as medical history, for any of these institutional forms we need our product to be HIPAA compliant.

There were various technical challenges that required trial and error of different iterations and alternative solutions before we found an adequate working solution. The first was that of paper detection. Initially, we were attempting to find the four edges of the page in the video feed, and then using the intersections of the lines to deduce the corners of the page, which we would need to perform homography and transform the perspective view of the page into a flat 2D plane. Another aspect that required iteration was the pen detection method. Initially we tried motion tracking the pen tip, but this required initialization at the beginning of use. We shifted to coloring the pen tip and then attempting to track that color in the video stream, but this was highly unstable due to the dependence on lighting conditions. Finally, we settled upon and polished an approach that used IR LEDS placed next to an IR camera pointed at the page, and a retroreflector sticker tip on the pen. We could then simply look for the brightest area in the IR video stream, and this gave us very reliable and robust results. The pen guidance method was also an area where we considered alternative methods. Initially it used text to speech to speak movement directions, but was repetitive and inaccurate. We then switched to an audible beep instead that gave markedly better results.

For the administrative interface, we chose to make an easy to use web application that an institution can log into to store their marked forms. The interface contains three main pages: a login page, a home page, and an upload form page. If the institution does not have an account initially they can also create an account by using their email address and a password. Once the user logs in or creates an account they can upload a form on the upload form page. The form will be rendered on the left hand side of the page and the institution user will then be able to draw boxes, called form fields, on to the form where a user will need to fill out information by clicking and dragging their mouse at the appropriate location. A box will appear on the right hand side of the page associated with the form field where the institution user will type in the associated description for the form field that will be read to the B/VI individual when using the smart clipboard. The home page stores the institution’s previous marked forms. They can click on the hyperlink and it will redirect them to upload form page with the denoted signature areas highlighted. If the institution wants to update the form they can remove any of the form field boxes or change the descriptions.

We initially built the administrative interface in a combination of javascript and HTML. However, since no established framework was followed initially, we were having trouble adding a login page and a home page. As a result, we decided to rebuild the web application using react. Using react, we were able to create 5 different views and 10+ components that were used for each page. We also used KonvaJS to create the dynamically drawn form field boxes. MongoDB was utilized to store the form field information, form images, and user login information.

The Forma clipboard is equipped with an infrared camera around which six 940mm IR emitting LEDs are mounted. Using SolidWorks, we modeled the viewing angle of each LED and determined the optimal angles for mounting such that the area of illumination on the page was maximized, giving us a more reliable image for pen detection. In order to increase versatility, we chose not to include any active hardware on the pen. Instead, we added a retroreflective tip which bounces off the infrared light and contributes to our detection algorithm.There are also 3 pull-up buttons mounted to the clipboard, which together allow the user to toggle guidance between different fields on the form. To adhere to our design goal of keeping Forma low cost, the mount itself was designed as a screw on attachment to a preexisting clipboard. Each component was 3D printed out of PLA and fitted with brass heat set inserts, which allowed us to keep the device lightweight.

Our pen detection software runs off the onboard Raspberry Pi 4, and can run at speeds greater than 20fps which gives great real-time performance and is suitable for capturing small movements in the hand. For our guidance algorithm, we process the image obtained from the IR camera in python to generate a set of audible instructions for the user, played through an audio jack. How this works is, we first normalize the pixels in the image to the 0-255 range, making the brightest pixels brighter and the darkest pixels darker. After this, we initialize a region of interest around the largest, brightest contour in the image, and track the region of interest using a KCF tracker. Once this region of interest has been initialized, we once again look for the largest, brightest contour, this time within the smaller region, allowing us to drastically reduce computation. At each timestep, we calculate this contour and use it to determine the pen tip position. Once the pen tip position is determined, a projective transformation is calculated between the image plane and the world plane, using the corners of the page as reference. We then apply this transformation to the pen tip to calculate the absolute position of the pen relative to the form. Combining this with the positions of the fields on the form, which we obtain from the database and frontend, we are able to calculate the distance between the pen tip and the target field and subsequently generate a corresponding audio queue.

We believe that since forms are initially created digitally that it will be easy for the institution to upload them to a web application. Manually denoting the form fields on the boxes is not ideal, but an institution user would only need to do this one time for each form uploaded and stored. In the future to remove the burden of the institution to denote all the form fields we hope to build a neural network that uses OCR to automatically find the form fields without any human intervention.

Prior to Forma, in order to check in a blind or visually impaired customer, institution help desk administrators would have to stop what they were doing, take time out of their day - not to mention jeopardize the privacy and independence of the customer - in order to help fill out a form. With an administrative interface, by uploading and tagging forms once, these minutes add up to hours saved. But numbers pale in comparison to the satisfaction gained by the blind and visually impaired individual.

Regarding the quantitative metrics that we were able to measure so far on our first full prototype of Forma, we have collected the following data:

Metric	**Result**
Weight	1.6 lbs/0.7kg
Battery life in use	6+ hours
Average time to reach form field*	Approx. 20 seconds
Average running frequency/framerate	Approx. 18 Hz/fps

* Self tested, and after some practice using Forma

Table 1: Test results

Based on our initial full prototype of Forma, we demonstrated it and its functionality to Dr. Prasad, our clinical advisor, and Dr. Nguyen, who will be in charge of the user studies we will undertake with Forma. The feedback we received was quite positive and deemed to potentially be helpful to blind and visually impaired users, especially with further work and iteration on the product. Some areas of improvement identified were the reliability of pen tracking, the ability to continue guiding the user while they were writing, and the ability to record and read out the information that the user was handwriting to verify that the information was entered correctly.

Based on these preliminary results and findings, we believe that Forma is on track to meet its stated original goals of allowing blind and visually impaired persons to fill paper forms with more ease, greater privacy, better independence, and less time. The technical goals were met in that Forma reduces the amount of time a user spends navigating the form, and the audible feedback we give is at high enough frequency to effectively guide the user about a form. We find that the auxiliary goals and constraints were also met, in that the device is portable, and can easily last through a full day of use on a single charge. These are crucial if Forma is to be used in a real-world environment such as an office or front desk of an institution.

For next steps to continue testing and verifying our first prototype of Forma, we will be conducting user trials, which have already been IRB approved. The goal will be to glean insight into key metrics to measure, verify, and improve:

- Average time to reach form field
- Ease of use
- Privacy
- Independence
- Time saved

For the final status of the project at the time of completing senior design and drafting this final report, we have completed our first fully working prototype and iteration of the Forma product with the aforementioned specifications and test results, which have shown great promise. We have been advised to look into patent protection, and so we will be investigating this also. We hope that this project can be continued and improved upon, whether by us following the user trials, or by another group enthusiastic about the mission upon which Forma was founded.

IV. Self-Learning

To build Forma, we used a variety of different topics ranging from computer vision to mechanical design. For our administrative interface we had to become familiar with javascript, react, and databases. A couple of us had built previous web applications in other classes and we used the client-server structure as a basis for our interface. We had to learn how to draw dynamically using a combination of HTML and javascript. To do this we ended up using a package called KonvaJS and studied a lot of documentation from their website. Building the smart clipboard required a lot more knowledge regarding computer vision, infrared cameras, microcontrollers, and hardware design. A few of our members had taken computer vision courses, but we all needed to learn about basic homography, pixel normalization, and the python package OpenCV. During iteration of our clipboard, members of our team did external research on HSV color detection and tuning and paper detection, including lane detection. For the spring semester, the bulk of self-learning was for pen detection. Our teammates put in a lot of effort researching alternative methods to detect a point that was resistant to lighting changes. This included using an infrared camera, which we ended up using for the final product. Our team also had to learn to use microcontrollers like the raspberry pi and integrate it with our original python scripts and an extra set of push buttons.

The most helpful classes taken were computer vision courses. These included CIS 580, CIS 581, and CIS 680. The knowledge learned was integral in helping refine our 2D transformation from the 3D pen location to its location on the page and for the infrared camera image processing. Normalization methods learned were also beneficial to help our product become more resistant to lighting changes. ESE 215 was also important for designing the push button circuitry and battery load for the microcontroller. For the administrative interface, CIS 450 was very helpful in designing the database retrieval and overall structure of the web application. Prior projects from that class were referenced to help us choose the appropriate keys and database and to start the client-server react scripts.

V. Ethical and Professional Responsibility

In terms of ethical and societal issues, our product aims to improve the quality of life for an underrepresented and disabled population. We hope our application will improve the quality of life of the visually impaired, through increased independence and access to new financial opportunities. The visually impaired suffer from increased rates of poverty and being able to apply to job openings or fill out disability benefit forms will aid them significantly. We are working with Dr. Prasad and Dr. Brian Nguyen to begin testing our product at the Scheie Eye Institute. Since we are working specifically in the medical space, we must adhere to HIPAA regulations. As a result, we chose not to store any patient information within our product. Additionally, we also need to design our solution to comply with ADA standards put forth by the Americans with Disabilities Act Standards for Accessible Design, which states that all electronic and information technology (like websites) must be accessible to people with disabilities. Through our testing feedback, we will gain insight from real users about how to improve the accessibility and ease of use of our product. In the future, we may need to improve the cybersecurity of the product, specifically in regards to the video stream, to keep our product robust enough to comply with HIPAA.

VI. Meetings

We met with our advisors less often in the spring semester than in the fall semester as were more focused on building the physical prototype. We emailed Dr. Weimer once or twice throughout the semester to give him updates on the project, whereas we met over Zoom with Dr. Prasad every other week. We also called monthly with a colleague of Dr. Prasad's, Dr. Brian Nguyen, to discuss the status of the IRB and to begin developing a study with the smart clipboard. In late March and April we started meeting in-person with Dr. Prasad to view the Low Vision Center and to demo the functionality of the smart clipboard. Since we were more focused on building the hardware and due to the constraints of the pandemic, we did not have as much time to speak with other stakeholders this semester. For most of our usability design questions, we discussed our ideas with Dr. Prasad and Dr. Nguyen. With their insight we chose to guide the user sequentially and use a combination of verbal audio feedback and tones.

All meetings were scheduled over email, reinforced through GCal event links, and delivered through Zoom meetings. Meeting minutes were taken over Google Docs and distributed to attendees afterwards.

VII. Proposed Schedule with Milestones

This Spring semester, our goal was to shift focus from user interviews and software development and focus on the hardware implementation of the clipboard. Because the original RGB camera implementation was not performing as intended, we needed to devise a new solution to detect the pen and paper, with a goal to have the pen detection working at least 90% of the time in a variety of lighting settings (indoors with lights on, indoors with natural lighting, harsh lighting, etc). Our ultimate goal was to create one working prototype of a clipboard that could guide the user to fill out a predetermined paper form (Women's Center form) by Demo Day. In addition, we also wanted to improve on the software by making the administrative interface more robust, such as including a login system as well as the ability to retrieve and upload multiple forms within a profile.

While a working prototype was the priority, a product is not finished until it actually satisfies the customer's needs. Therefore, we wanted to test the finished prototype with blind and visually impaired individuals from the Scheie Eye Institute to get their feedback closer to the end of the semester, and to ensure that it would take less than an hour for an individual to fill out the predetermined paper form. Our proposed milestones included key tasks for software and hardware implementation are shown in Table 1 in the Appendix.

VIII. Discussion of Teamwork

With all four of the team members back on campus this semester, and living in pairs with each other, we naturally gravitated towards tag-teaming one pair on software-related tasks and another pair on hardware-related tasks, since we still could not physically work together. While Maggie and Sadhana worked on software, Chris and Yan worked on hardware which kept us more organized and focused on our responsibilities.

We used similar methods of communication as last semester, and continued using a combination of Zoom, Google Calendar, and Messenger for communication within the team as well as Zoom with our advisors and the Senior Design instructors. Meeting weekly, we would first go through tasks that we had completed that week and then discuss what the priorities were for the next, pointing out deadlines within these meetings. Because we divided ourselves into subgroups responsible for hardware and software and lived with each other, our workflow was a lot faster this semester compared to last semester, as we could just sit and code/tinker in the same room together and get immediate feedback. When either subgroup was stuck, we would Zoom call each other and discuss as a group how to solve the problem which was fruitful since others could look at the problem with fresh eyes.

In terms of division of tasks, we tried our best to split the work equally in terms of interest, time, and expertise, as shown in Table 2 of the Appendix. For example, owning a 3D printer and being familiar with SolidWorks, Chris was responsible for the 3D modeling and printing of the camera and microcontroller housing. Yan was responsible for creating the button controller as well as the IR camera LED ring light. Maggie, having experience with React.js, was responsible for refactoring the frontend code, and Sadhana, familiar with databases, was responsible for implementing the backend database connection with MongoDB. Chris and Sadhana also had prior experience with Computer Vision through CIS 581 and other courses and contributed to the pen and paper detection. While our roles were distinct, this allowed us to be productive and take ownership over our specific tasks while also learning from each other.

IX. Budget and Justification

Part Name	**Price**
Vibration Motors	$5.82
IR LEDs	$6.13

Reflective Tape + Pi NoIR Camera	$34.65
IR Pass Filter	$15.89
Wall Power Adapter	$9.53
PiCamera Ribbon Cable	$8.47
Micro HDMI Adapter + Mini HDMI Adapter	$15.21
Clipboard	$12.61
Raspberry Pi 4 B + Raspberry Pi Zero W + USB Hub + Camera Flex Cable + Pi Camera v2	$103.00

Grand Total:	**$211.31**

X. Standards and Compliance

Since our project is both a hardware and software product geared towards medical settings which we intended to test with human subjects, we needed to comply with HIPAA, FDA, as well as IEEE and IEC standards to ensure we protected personal data, privacy, and security and to ensure our product met state of the art technology standards.

For HIPAA, we needed to comply with HIPAA 45 CFR 46, HIPAA 45 CFR 160, which protect human subject data and data privacy for personal health information, respectively. Because we wanted to complete a study to analyze the performance of the product, we also needed to comply with FDA 21 CFR 56 and FDA 21 CFR 50, which outline policies for Institutional Review Boards and protection of human subjects. In the study, this meant anonymizing our user interviews and in our product, this meant not storing or sending any personal health information on the hardware or software.

On the hardware side, because we were using off the shelf components like the Raspberry Pi, LEDs, IR camera, etc., we didn’t need to specifically comply with any IEEE standards on that front; however, in terms of software, we did need to comply with IEEE P7002 and IEEE STD-23026 which maintain data privacy, security, and user information on web applications. We ensured this by creating a login system with encryption for passwords and not storing any user information, since the administrative interface functions just as a storage and retrieval system for forms.

XI. Work Done Since Last Semester

We made a lot of progress since last semester in terms of both software and hardware implementation to create our final prototype. Most significant was the hardware implementation, which included developing a reliable pen and paper detection system with the IR camera and active lighting using LEDs. In addition to implementing reliable pen and paper detection under a variety of lighting conditions, synthesizing all the hardware components - Raspberry Pi, IR camera, LEDs, audio feedback, buttons, and the clipboard itself - took up most of the effort and finalizing this allowed the project to come together in the last few weeks before Demo Day. Ensuring that the parts worked took an extra two weeks closer to the beginning of March because some hardware components were faulty while others took more time to arrive. While we waited, we worked on implementing the fixed homography for the paper detection algorithm as well as the sequential input algorithm to guide users to the next input field. On the software side, we also made drastic improvements in the modularity of the software architecture by refactoring the original pure HTML and JS code into a React.js app. This allowed us to easily create new pages and components on a whim as well as a login system with user profiles and integration with the MongoDB database. To accomplish both sides of the project, we worked in parallel and regularly checked in with each other to discuss any blockers. When we were happy with a working prototype prior to Demo Day, we created a video demo that encapsulated the problem, vision, and solution of our project.

XII. Discussion and Conclusion

Over the course of the last year, we as a team have ideated, researched, prototyped, and built Forma, a device that allows the blind and visually impaired community to fill paper forms faster, easier, and more independently. From the very beginning, we hoped to work on a hardware and software engineering project that helped an underserved community. Building Forma allowed us to do this through empathizing with users as well as stretch the engineering knowledge we've gained throughout the last four years. Forma works by allowing blind and visually impaired users as well as administrators at institutions to fill out paper forms with ease through a two-part hardware-software solution: 1) a smart clipboard that guides the user through the inputs in a form through audio feedback, and 2) an administrative interface that allows administrators to upload forms, tag them with inputs, and save them for future use.

In creating the prototype, we each took ownership over the particular skills that we were confident in and wanted to develop. On the hardware side, Chris and Yan fashioned an IR camera, LED light, and reflective tape pen detection system, which uses reflective tape that can be applied to the tip of any pen for detection by the IR camera. The LEDs provide active lighting to provide extra reflection for the pen and we chose this system because of its tolerance in low and harsh lighting conditions after discovering that the RGB camera was unreliable in different lighting conditions. Chris 3D modeled and printed the parts for the camera mount while Yan created the circuitry for the LEDs as well as the push buttons that allow the user to toggle between fields and exit from the program. On the software side, Maggie and Sadhana were responsible for creating the web application for the administrative interface, which included a login system and database for storing the forms and their inputs. This was done through a React.js web application and the database was hosted on MongoDB. On the algorithms side, for detecting the clipboard and pen, we all collaborated as a team, writing various parts of the code and testing it independently. Once the prototype was completed, we tested it with our team members and demoed to our medical advisor who will be using Forma in a future IRB study. Overall, we are proud to have been able to build and test a challenging software and hardware project that helps the blind and visually impaired fill out forms faster, easier, and more independently, all while working remotely.

As we continue to refine Forma further, we foresee potential challenges in marketing towards the institution. Although it is only a one time event, the manual labeling of the forms is a little work intensive for the institution. To remedy this, we hope to remove the manual identification of form fields from the administrative interface so that there will be less of a burden on the institution. We aim to do this by using OCR and building a machine learning model that can identify form fields, such as checkboxes or blank lines, and the text associated with those form fields. This will hopefully make the product more appealing towards the institution as the institution would then only need to receive a clipboard from Forma and just upload the forms that would need to be filled out. Another challenge we may face is securing our IP. Forma uses novel technology and we want to ensure that our product's technology is protected, so that it will be easier to commercialize in the future. As a team, we are discussing how best to go about this and may use Penn's legal resources. Finally, as we begin testing Forma with B/VI users, we will get a lot of feedback which will adjust the design of our product. Initially, we had recognized that lighting would be a challenge and switched to an IR camera as a result. With user testing, we will see how well the IR camera and our product performs in other adverse environments which will help us further iterate our product.

Working on Forma has been a great experience for all of us and we have learned a lot along the way. Overall, we believe the most important lesson we have learned is how to work as a team. During our Spring semester junior year, we had just formed our team and did not know how to work together efficiently yet. This had led to some initial conflict as we were trying to find a topic for our project and working over Zoom, but from those experiences we developed our communication skills which would prove to be crucial as we began building our prototype. We defined clear tasks for each individual and used the "divide and conquer" approach to work on the prototype so we could build as efficiently as possible. As we move forward with our careers, teamwork will always be an important aspect and working on a long-term project like Forma has taught us invaluable skills that we will need. Additionally, we have learned the importance of planning and iterative design. Initially, we spent significant time designing our product as a smart pen with a camera on top and assumed that would be our final design. This assumption proved to be wrong as our initial design was too advanced for the limited time that we had, so we had to return to the drawing board and think of new designs. This happened repeatedly throughout the project, as we ran into new problems and taught us that no design is final. There will always be new bugs or issues that arise and redesigning is part of the iterative process to refine the product. Without these iterative steps, we would have never settled upon the smart clipboard design and built the product we have today.

XIII. Appendix

Task	Completion
Migrate and test code on Raspberry Pi	2/20
Brainstorm and test way to improve pen and paper detection (working at least 90% of time across multiple lighting conditions)	3/10
Add login system and form retrieval capability to frontend	3/10
Build IR camera and active lighting LED ring	3/14
Implement audio feedback for physical clipboard prototype	3/14
Add buttons for controlling form input (back, forward, done) with delay of less than half a second	3/17
Build and complete working clipboard prototype	3/29
Create video demonstrating problem and solution	4/6
Test product and showcase to stakeholders, with individual able to fill out form in less than an hour, alone	4/7 (Demo Day), 4/13

Table A: Planned Milestones for the Spring semester

Name	Contribution
Chris Zhang	• Created video demonstrating problem, vision, and solution • Implemented IR camera-based pen and paper detection algorithm with fixed homography • 3D modeled and printed attachment for IR camera and microcontroller housing on clipboard • Migrated and tested code on Raspberry Pi • Tested clipboard at Scheie Eye Institute
Maggie Zhang	• Coordinated schedules and meetings • Refactored frontend code in React.js • Created login page for administrative interface • Recorded speech for audio feedback • Migrated and tested code on Raspberry Pi
Sadhana Marikunte	• Refactored frontend code in React.js • Set up form retrieval in frontend from MongoDB • Coded ordered form input sequence • Created login page for administrative interface • Migrated and tested code on Raspberry Pi

	• Fixed bugs in frontend form display
Yan Li	• Wired buttons for controlling form inputs • Soldered LEDs for ring light on IR camera • Prototyped audible pen guidance and text-to-speech • Drafted business plan, business analysis, cost breakdown • Migrated and tested code on Raspberry Pi • Tested clipboard at Scheie Eye Institute

Table B: Summary of contributions by each team member