

XPEN - Report



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Please refer to the “[Maker Portfolio](#)” video for visual demonstrations.

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I. Introduction

Welcome to the XPEN portfolio, where you will discover an in-depth look at XPEN's development journey, innovative features, and transformative potential.

XPEN started out as a joint effort with my co-founder, Bilal. Beyond the technical successes, I am immensely appreciative of the path it offers—one that sharpened my soft skills, including teamwork, resilience, and creative problem-solving, as well as my technical hard skills in engineering and software development. XPEN has been a defining chapter in my development as a team player and an inventor.

Note: If the embedded video link does not function properly, you can access it directly using the following link: <https://youtu.be/yRhLPX8apYE>.

II. What does it solve?

Problem	How XPEN solves it
Overwhelming note-taking Keeping up with fast-paced lectures while taking detailed notes can feel like an impossible juggling act.	XPEN steps in to make things easier by capturing lectures (video, audio, or pictures) and generating concise AI summaries. Now, students can focus on understanding concepts in real time without stressing about missing important details.
Lack of personalized learning tools Most learning tools are generic, and that rarely works for anyone.	XPEN acts like a personal learning coach, letting students ask questions, get adapted guidance, and interact with classroom material in a way that actually fits their style of learning.
Challenges for students with disabilities Traditional note-taking methods can leave students with motor or learning disabilities behind.	XPEN addresses this by mimicking handwriting, signing documents, and adjusting pressure for different languages. It's designed to make learning accessible and inclusive for everyone.
Time and resource Inefficiency Manually rewriting and organizing notes takes time that could be better spent learning.	XPEN automates it all, turning text, images, videos, and audio into neatly handwritten notes. It saves hours of effort and makes staying organized a breeze.
Emotional disconnect in learning tools Digital tools can sometimes feel impersonal, making the learning experience less engaging.	XPEN changes that with dynamic expressions and emotional responses, making interactions feel natural and even fun.

Global accessibility and customization Most tools are expensive, limited in languages, or not built for diverse needs.	XPEN flips the script with an affordable price (starting at \$99) and features that adapt to different cultures, educational contexts, and even unique needs like calligraphy or multilingual accessibility.
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III. Core functionalities

Functionality	What it does
Handwriting mimicry	XPEN replicates human handwriting with precision, allowing students to create handwritten notes, recreate signatures, and personalize documents.
AI-Powered Summaries	Generates concise, AI summaries of lectures by integrating multimedia inputs like video, audio, and pictures.
Real-time learning coach	Serves as an interactive study assistant with features like: • Real-time Q&A sessions. • Multimodal input processing (audio, text, and visual). • Emotionally aware responses using dynamic expressions ("eyes").
Dynamic pressure mechanism	Adjusts nozzle height and pressure for: • Calligraphy strokes. • Space between words • Dynamic Physical expressions ("crouching," "jumping") • Mimicking personalized signatures.
Multilingual accessibility	Supports note-taking and summarization in English, French, Arabic, and Spanish (tested and trained languages)
Environmental adaptation and calibration	Ensures precision despite environmental factors like humidity.
Modular and user-friendly design	Easily integrates new functionalities and hardware upgrades (view "Core Components & Functioning").

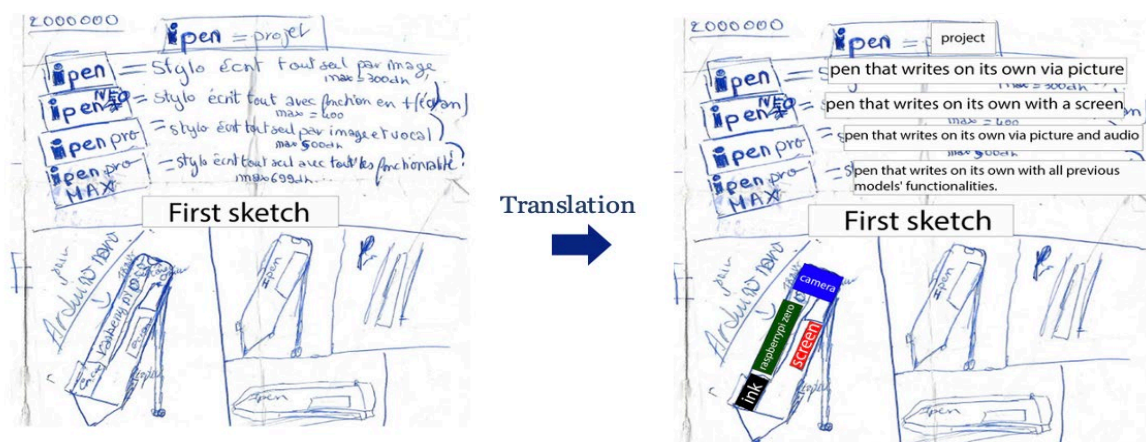
IV. Nomenclature

Type	Term	Meaning
Technical terms	TPU belts	Flexible, durable belts made of thermoplastic polyurethane used for precise movement.
	Stepper motors	Motors that move in precise steps, essential for XPEN's accuracy.
	Rack-and-pinion mechanism	Gear system converting rotational motion to linear motion, used for the Z-Axis.
	Z-Axis	Vertical movement axis in XPEN, used for lifting, spacing, and calligraphy.
	Nozzles	The writing components that deposit ink.
	Linear shapes	The elongated design of XPEN, ensuring stability and efficient functionality.
Software and OS terms	Buildroot	A tool for creating embedded Linux systems, forming XPEN's custom OS.
	GPT-3.5 API	AI model used for generating text and analyzing emotions.
	Google APIs	Tools for text-to-speech, speech-to-text, and optical character recognition.
	OpenAI APIs	AI platforms powering XPEN's natural language understanding and responses.
	Humanizing APIs	Systems adding natural pauses and intonation to make XPEN's interactions lifelike.
General technical concepts	Calibration system	Automated process ensuring XPEN's precision.
	Edge detection	Sensors detecting edges to enable XPEN to reverse direction automatically.
	Elasticity	TPU belts' flexibility
	Dynamic expressions	XPEN's "eyes" feature to display emotions.
	Multimodal capabilities	Ability to process and combine audio, text, and images for seamless interaction.
Project management	Custom OS overlay	An interface layer tailored to XPEN's hardware and software integration.

t and design terms	Rev X.Yz	Versioning system for XPEN prototypes and iterations (e.g., Rev 4.5a).
Miscellaneous	GLS jumping	XPEN's "bouncing" feature adjusts nozzle pressure for calligraphy and handwriting mimicry, named after the suspension of the Mercedes-Maybach GLS.

V. XPEN Journey

The first sketch: where it all began



This is the very first version of XPEN (then called IPEN) that Bilal and I sketched during a physics class. Looking back, it is incredible to see how far the project has come since then! At the time, we imagined the device standing upright, but we quickly ran into challenges: there was not enough space for the steppers or the servo motors we planned, and, honestly, we did not even know where to fit them.

Despite its flaws, this first sketch laid the groundwork for some of XPEN's core components, many of which are still part of the design today:

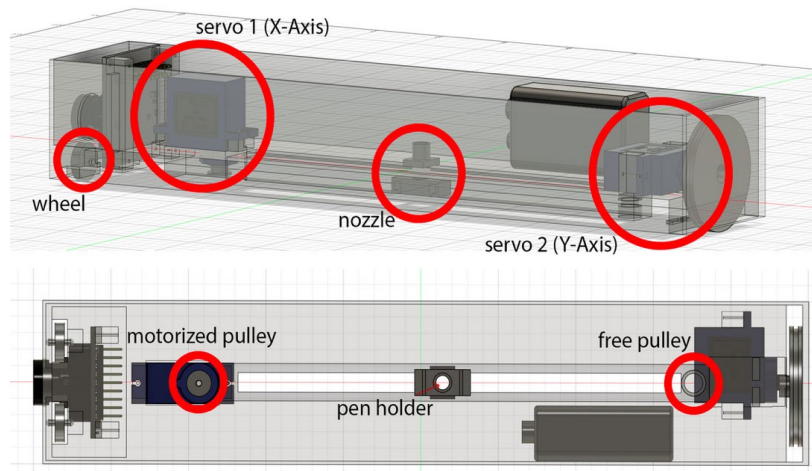
- **Motherboard** located in the shell's back.
- **Camera** for capturing input.
- **Ink reservoir** for handwriting mimicry.
- **Screen** for user interaction.
- **Linear shape**, giving XPEN its signature streamlined design.

However, this version did not account for the complexities of an upright device, like weight distribution, center of mass, and overall user experience, which all make the original design both impractical and nearly impossible to implement.

It is worth noting that even in these early stages, we were already brainstorming marketability! You will notice four different versions of "IPEN" in the sketches, including a standard version we envisioned starting at an affordable price of \$30!

1. Relevant Prototypes and Progress

The first prototype designed on CAD



This version never really worked due to two key issues: the nozzle and the Y-axis.

1- The Nozzle

At the time, we were relying on rubber bands to move it—neither knowing about TPU nor having access to it. This made the nozzle extremely imprecise, causing frequent stuttering and functionality failures.

2- The Y-Axis

The problem here was clear: we used only one powered wheel without a distribution shaft, which caused the prototype to spin in place instead of moving in straight lines.

That said, not everything was a failure! One element from this prototype survived and is still in use today: the pen holder. Without a proper nozzle, we cleverly adapted by repurposing Bic Cristal pen nozzles.

2. All prototypes before the current XPEN



Here are the eight prototypes that led to the current XPEN, each teaching us something valuable:

1- Prototypes 1 to 3: Early practice. We were experimenting and learning how to make the device write.

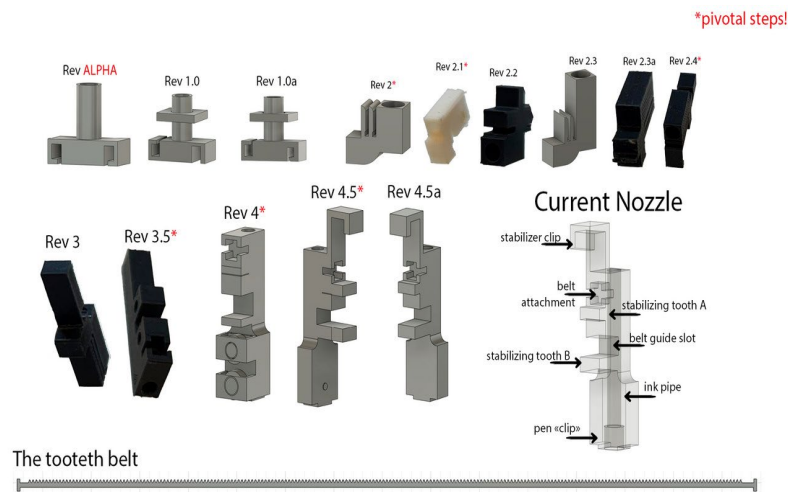
2- Prototypes 3 to 6: Focused on Y-Axis movement but failed because PLA wheels weren't suitable for the task.

3- Prototype 7: Our first success in making the nozzle move (demonstration: ["Maker Portfolio"](#) from 0:11 to 0:19).

4- Prototype 8: The first "serious" prototype. It could draw lines but was still too imprecise. This was the last version to use servo motors and the first to introduce caterpillar tracks.

I'll dedicate "Core Components & Functioning" to the recent XPEN family.

3. Timeline of the nozzles



The nozzle has undergone numerous iterations to balance precision, durability, and practicality. Each version reflects lessons learned, design refinements, and new challenges solved. Here is how it evolved:

Rev ALPHA: My first-ever nozzle! It never left CAD but introduced the early pen clip design.

Rev 1.0 & 1.0a: Experimental designs that did not function well but provided valuable early lessons.

Rev 2: A major milestone! This was the first standing vertical design, featuring a TPU toothed belt with two thin slots for tooth stabilization.

Rev 2.1: Introduced a stabilization hole and the first iteration of the current belt attachment system.

Rev 2.4: Pivotal update! Added the stabilizer clip, a feature still used in the current nozzle design.

Rev 3.5: Marked the transition to the modern XPEN family. This was the last nozzle to use stem stabilization.

Rev 4: Introduced stabilization rails, making it extremely stable but noisy, costly, and impractical due to grease requirements.

Rev 4.5:

- A transitional design combining the best features of previous versions:
 - Belt attachment from **Rev 2.1**.
 - Stabilizer clip from **Rev 2.4**.
 - Shape from **Rev 3.5**.
 - Tooth stabilization from **Rev 2**.
 - Pen clip from **Rev ALPHA**.
- Eventually replaced for improved strength.

Rev 4.5a:

- The culmination of everything I have learned. This is the current and strongest iteration.
See the diagram for a breakdown of its features.

4. Challenges Overcome

Creating XPEN was anything but easy. Each challenge forced us to think outside the box, adapt quickly, and learn something new from every failure. Here are some of the biggest obstacles we faced and how we tackled them:

Challenges	Solution
Resource limitations	Living in Morocco meant many essential tools were out of reach—stereolithography machines, PCB prototyping kits, you name it. We made do by cutting TPU belts by hand, building custom detection pads, and shaping toothed pulleys ourselves.
Import delays	Getting parts like 3D printer filaments, stepper motors, and motherboards through customs was a real challenge. At one point, I even had to appeal directly to the Head of Importation Services to unlock shipments. That experience taught me a lot about persistence and negotiation.
Legal and patent issues (Morocco's patent office initially rejected XPEN's software-based approach, as it didn't fit traditional hardware patent frameworks.)	XPEN's software-based design did not fit Morocco's traditional hardware patent frameworks, so the patent office initially rejected it. We pivoted, focusing on the hardware instead, and convinced them to assign a team to help us navigate the process.
Humidity in Casablanca	TPU belts, which are critical for XPEN's movement, absorbed moisture and became more elastic, messing with precision. To fix this, we built a calibration system that adjusts elasticity after every restart,

	ensuring XPEN stays accurate no matter the environment.
Stability and movement issues	Our early prototypes used caterpillar tracks, but they made XPEN pitch under its own weight. Switching to TPU wheels with PLA cores solved the problem, improving both balance and adhesion.
Data loss before Investor Meeting	The night before a big investor presentation, we accidentally deleted XPEN's custom OS overlay during testing. With no time to rebuild it, we pivoted to Debian and used our web-based UI to keep things running. As tough as it may sound, it is also proof that web UIs have their merits too!
Time constraints	Balancing school and XPEN development was always a challenge. Bilal and I split tasks, and held weekly progress meetings, ensuring we met the deadlines we set. It was not easy, but the effort was worth it for the progress we made together.

5. Key Learnings

1- Balancing perfectionism with progress

One of the most valuable lessons came from our mentor Didier Tranchier, who often said, "Too much tech, not enough profit." Early on, I focused too much on perfecting every feature, which slowed down progress.

Key learning: Functionality first, polish later. Progress happens when you keep moving, not when you get stuck chasing perfection.

2- Resourcefulness and problem solving

Operating in Morocco meant no fancy tools—no reflow ovens or stereolithography printers. When we needed to solder tiny PCB components, a clothes iron became our reflow plate.

Key learning: Limitations are most of the time a blessing rather than a real constraint. If the perfect tool is not available, make one.

3- Mastery of cross-disciplinary collaboration

XPEN demanded the perfect marriage of hardware, software, and design. I managed the hardware (like integrating X, Y, and Z axes), low-level coding, and the "eyes" feature, while Bilal handled software, AI, and processing like OCR and text-to-speech. Key learning: Collaboration is as much about splitting tasks as it is about making the pieces fit seamlessly.

4- Effective time management

Balancing school and XPEN felt like spinning plates, but structured weekly meetings

kept us on track. By breaking tasks into small chunks, we made steady progress without dropping any plates.

Key learning: Clear timelines and teamwork keep even the most ambitious projects from falling apart.

5- Resilience

XPEN's journey was far from smooth, with unexpected challenges at every step. From breaking the 3D printer frame the night before a critical meeting with the patent office to spending nearly a year iterating through 20 different prototypes to make a single feature work, resilience became a cornerstone of the project. Key learning: It is only over when you pull the plug—literally. Whether it was rebooting XPEN at 2 a.m. or holding the frame together with duct tape mid-meeting, resilience sometimes meant laughing at the absurdity of the situation and diving back in.

6- The importance of user-centered design

Our first prototypes? Big, clunky, and all about function over form. However, feedback taught us to prioritize usability alongside performance.

Key learning: As obvious as it may sound, we have to listen to our users—they will tell us what works and what does not.

7- Embracing scalability

Didier's mantra was simple: "Think bigger," so we did. XPEN went from being a single device to a tool that could adapt—whether it is helping students in classrooms or supporting assistive tech users.

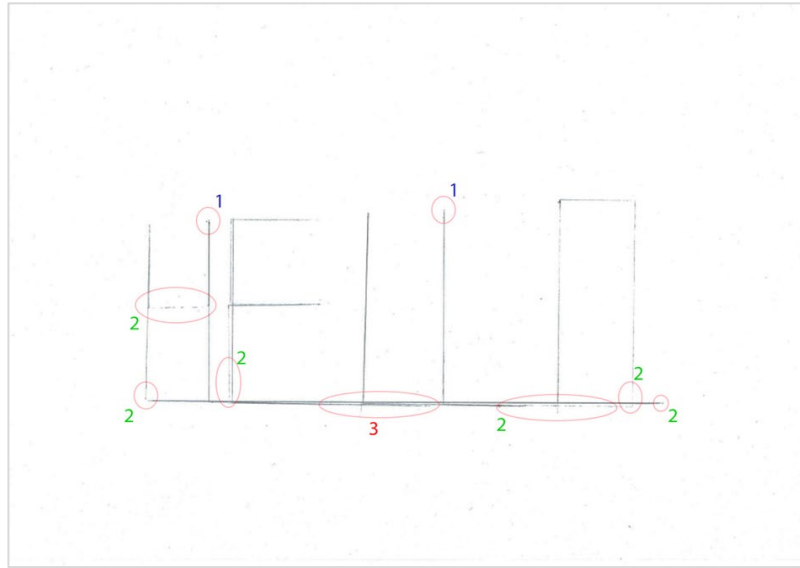
Key learning: Scalability is more about building smarter rather than doing more.

8- Technical proficiency with practical applications

Building XPEN was like taking a masterclass in everything: mechanical design, GCODE optimization, AI integration, and stepper motor systems. But the real trick? Making all that complexity practical.

Key learning: The best designs simplify the complex, not the other way around.

6. What I learned from XPEN's first word



On May 2, 2024, XPEN wrote its very first word: Hello. Was it perfect? Absolutely not—but it was a start, and more importantly, it taught me a lot. Here is what went wrong (and what we did about it):

1. Uneven H strokes:

The second line of the “H” was too long, making it look like XPEN was pitching back and forth like a boat on caterpillar tracks. To make things worse, writing over the same line twice boldened the first stroke.

Key learning: We swapped the caterpillar tracks for TPU wheels, which gave us much better stability and grip.

2. Dotted H line:

The horizontal line of the “H” came out dotted because the nozzle was not applying enough pressure near its starting point.

Key learning: We adjusted the Z-Axis to have a range from -0.5mm to +4.5mm, making sure the pressure stays consistent no matter where the nozzle starts.

3. Drifting lines:

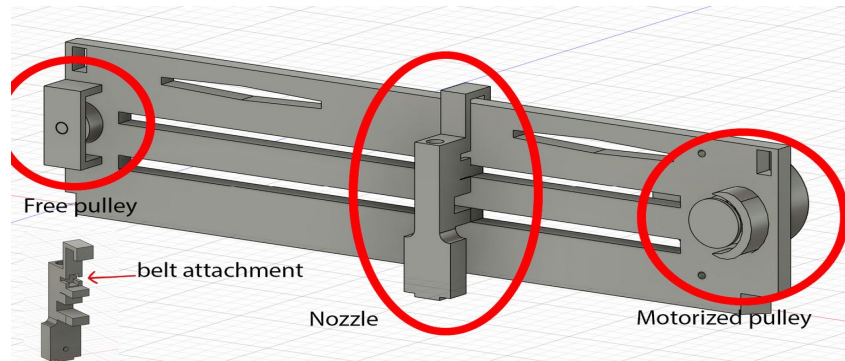
XPEN could not stay on track. It drifted off its path at high speeds because the caterpillar tracks could not handle the device’s 700g weight.

Key learning: Adding a real-time camera system to correct trajectory is now on our to-do list (still a work in progress).

And that bold bottom line? That is just the pre-print calibration (more information in the “calibration system” section). It was not perfect, but it was progress, and that is what mattered most.

IV. Core Components & Functioning

- **X-Axis**

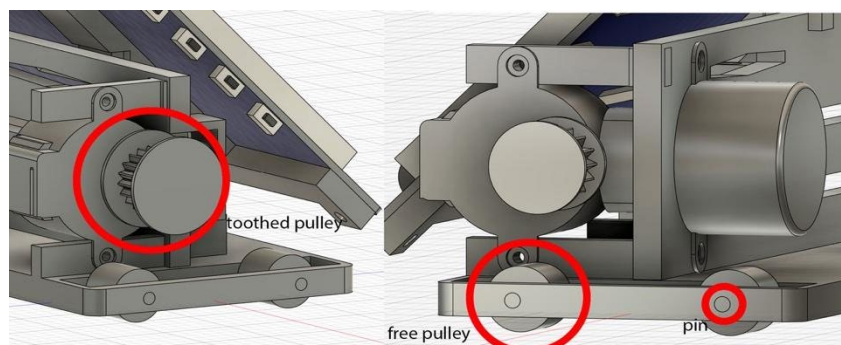


Getting the nozzle's slide to move smoothly was one of our toughest challenges. After countless iterations, we landed on a design that worked: two sturdy rails for stability and a top clip to keep everything from wobbling. (You can see these tweaks in action in the "[Maker Portfolio](#)" video.)

For the motorized pulley, we paired a 28BYJ-48 stepper motor with a 24-tooth pulley—a carefully calculated ratio to balance precision and torque. Why torque? At 700g fully loaded, XPEN needed every ounce of that energy to function properly. Lastly, to maintain tension and prevent slippage, a free pulley keeps the belt tight, ensuring consistent movement.

The nozzle itself came with its own set of challenges. The belt attachment point, located in the bottom-left corner, had to be carefully designed to fit the nozzle's dimensions while working within the constraints of the overall system. (For more on how we solved those issues, check out the nozzle section!)

- **Y-Axis (caterpillar version)**

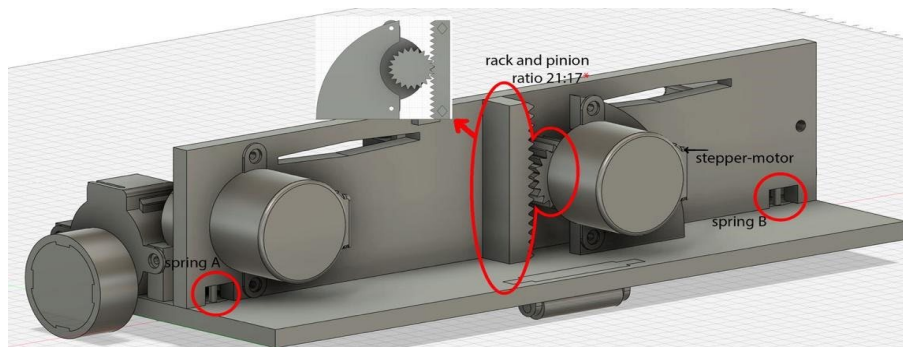


The caterpillar Y-axis design is simpler overall but went through numerous prototypes!

It features a toothed pulley with 38 teeth, along with two free pulleys to tighten the caterpillar. The toothed design adds torque, which was necessary because, in earlier versions, the caterpillar would slide when XPEN was fully loaded (again, up to 700g!).

You might also notice two pins in the design—these are a quirky yet practical way to insert the caterpillar before fully closing XPEN.

- **Z-Axis**

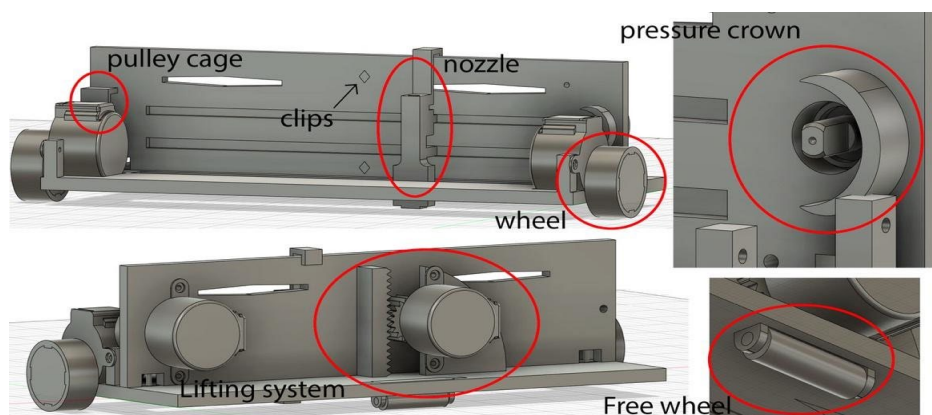


This is my favorite part—where XPEN truly jumps! Why "jumps"? Because to create spaces, XPEN lifts itself, ranging from maximum pressure (-0.5mm) to $+4.5\text{mm}$ to lift the nozzle. This functionality is also essential for languages like Arabic and Mandarin, which require added pressure at the start for calligraphy strokes.

Now, let us talk about the rack-and-pinion system. We tested multiple gear ratios—1:1, 2:1, 15:14, and our current 21:17. After experimenting, we landed on the 21:17 ratio as the perfect balance of speed, accuracy, and strength. Why strength? XPEN's significant weight means considerable torque, and the 21:17 ratio was the only setup that could overcome the torque limitations of the 28BYJ-48 stepper motors with their 64:1 internal ratio.

Finally, the springs: XPEN's design is not perfectly symmetrical, so we used a 3:2 ratio between Spring A and Spring B to counterbalance the 38g stepper motor on one side. This clever adjustment keeps XPEN stable and ensures smooth operation during every lift.

1. Current prototype



Here is the latest XPEN, featuring a new Y-Axis system and Z-Axis system, while still using the previous X-Axis!

- **X-Axis:** No major changes, but the pressure crown is worth highlighting. It ensures TPU sticks firmly to the pulley teeth, significantly enhancing precision and reducing slippage.

- **Y-Axis:** Completely redesigned! To fix the pitching issue we mentioned earlier, we have switched to TPU wheels. These combine a PLA core for shape and a TPU ring for adherence. Additionally, a TPU free wheel at the front stabilizes the system during rapid movements.
- **Z-Axis:** I have already highlighted this, but let us focus on its integration with the X-Axis system. To manage vertical movement, the Z-Axis actually lifts and supports the entire X-Axis system, as it is built directly onto it. The rack and pinion drive this motion, ensuring smooth and precise operation across both axes.

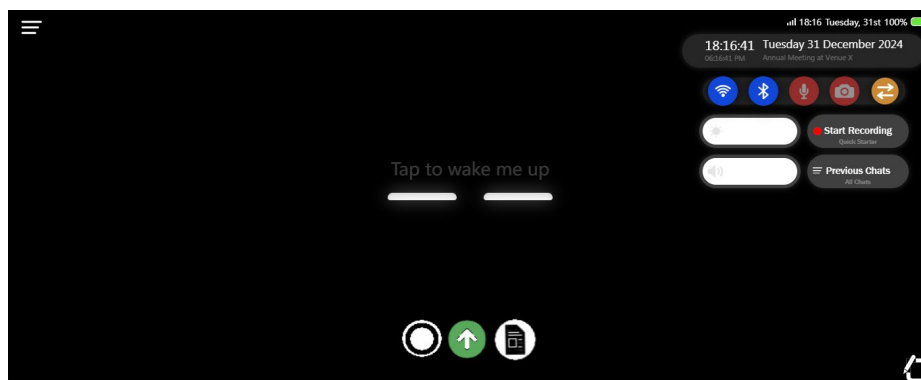
2. Current design



It took a lot of prototypes, but here we are! This version does not have handwriting capabilities yet, as I have not integrated them into this small form factor (4.7x3.1x3.2 inches), but there is still plenty to showcase:

- **Screen:** A 4" touchscreen serves as the user interface and communication hub.
- **Camera:** Hidden in the back within the X logo (our signature design). The X also has LED diagonals that softly blink when recording for privacy.
- **Connectivity:** XPEN includes two Type-C ports for communication and document imports, one for charging, and a 3.5mm jack for audio.
- **Cooling Capabilities:** Inspired by the Mac Mini G4, the cooling is fully passive. Air enters from the sides, passes through the CPU radiator, and exhausts through the top.
- **Modification-Friendly:** XPEN features easily accessible clips, making it simple to open and modify as we continue development.

3. Conversational capabilities and UI



XPEN makes learning feel personal, natural, and intuitive. Here is how it works:

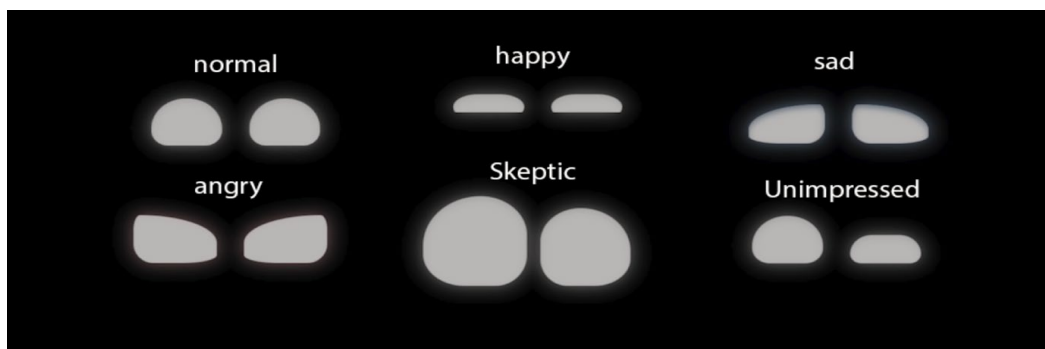
- **Privacy first:** XPEN's microphone and camera stay off by default and only activate when you turn them on, giving you complete control.
- **Wake-up feature:** Just say "XPEN," and it is ready to help, always feeling within reach when you need it.
- **Multimodal capabilities:** Whether it is audio, text, or visuals, XPEN processes everything in real time, making interactions flexible and seamless.
- **Lifelike interactions:** With emotion detection and natural pauses, XPEN's responses feel like they come from a thoughtful, human-like assistant.
- **Multilingual support:** XPEN understands and communicates in English, French, Arabic, and Spanish, making it accessible and adaptable to diverse users.

XPEN integrates multiple tools to power its conversational flow:

- **Google Speech-to-Text:** for voice input processing.
- **GPT-4:** To generate contextual and intelligent responses.
- **Our humanizing tool:** Adds natural pauses and intonations to make interactions feel more lifelike.
- **Google Text-to-Speech:** For delivering natural-sounding replies.

Additional tools enable emotion detection, real-time adaptability, and multilingual functionality, making XPEN a highly capable and personalized learning companion.

4. Eyes Feature

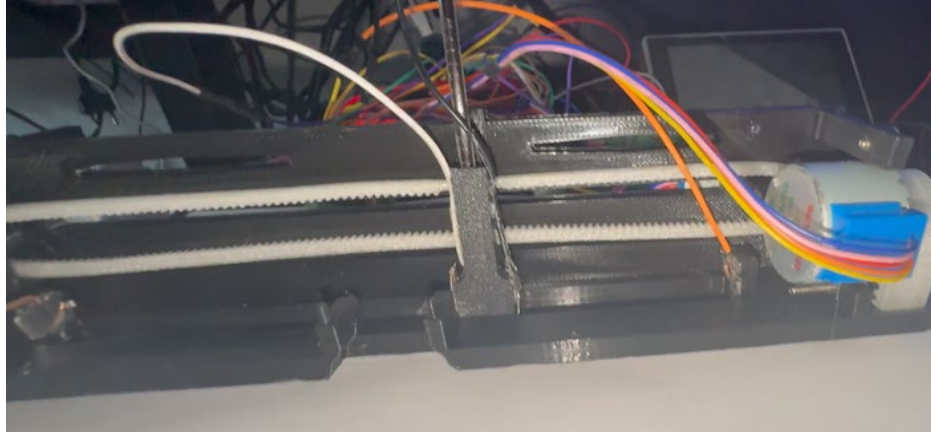


XPEN's "eyes" add an emotional dimension to the user experience, making it unique among digital assistants.

- **Visual Communication:** XPEN uses its eyes as a primary mode of interaction, improving the human-machine connection.
- **Emotion Detection:** By analyzing the text answer, XPEN infers the appropriate emotion and reflects it through its eyes, adding personality and proximity to the user.
- **Efficient Design:** Before activating the eyes feature, XPEN uses Tesseract locally to verify if images contain text, saving precious (and costly!) API calls. Once verified, OpenAI APIs handle text generation, and Google APIs manage text extraction, ensuring smooth and cost-efficient performance.

The eyes feature was the most debated (and reworked) part of the project. Perfectionism was mostly our enemy, causing delays and wasted time. What did I learn? Sometimes, good enough is good.

5. Calibration system



Why do we perform calibrations?

The toothed belt is made of TPU, a material that absorbs water, causing its elasticity to change over time. To maintain precision, after every restart, XPEN runs a program to count the steps required to move across 158.5mm. We then divide this distance by the step count (usually 1940-1970 steps) to calculate its precision.

How do we detect the sides?

Instead of using buttons (which require too much force), we came up with a quirky solution: two metal pads with copper rings are linked to GPIO inputs. The nozzle has two grounded metal pads, creating a "short circuit" when contact is made (on pins 16 & 17), signaling the program to stop counting steps and reverse direction.

What about the Y-Axis?

Y-Axis calibration is only performed once per prototype since the caterpillars are mechanical and maintain accuracy under varying conditions.

V. Technical Specifications

Category	Type	Specification
Mechanical system	X-Axis	80μm precision, TPU-toothed belt, stepper motor (28BYJ-48).
	Y-Axis	110μm precision, TPU wheels with PLA cores for stability, stepper motor (28BYJ-48).
	Z-Axis	0.1mm precision, Rack-and-pinion system ratio 21:17, dual spring ratio 3:2.

	Materials	TPU for belts/wheels (flexibility), PLA for structural components, and ABS for mechanical components.
Electronics	Processor	Raspberry Pi 4B for core operations; supports a custom Buildroot-based OS. (Broadcom BCM2711, Quad-core Cortex-A72 (ARM v8) 64-bit SoC @ 1.8GHz w/ 2GB LPDDR4-3200 SDRAM)
	Motors	4x 28BYJ-48 with 64:1 internal gear ratio.
	Sensors	Handmade copper detection pads for edge calibration.
	Camera	1x OV5647 (5MP) 1x IMX462 (2MP) (for testing we used the raspberry pi camera module)
	Microphone	MAX9814
Software	Operating system	XUI (our custom OS),
	Programming languages	Python, Flask, HTML, CSS, JS, C, Assembly, C++.
	APIs & Libraries	Google APIs (speech-to-text, text-to-speech, Gemini Pro Vision), OpenAI GPT-4 and GPT-3.5 Tesseract, FFmpeg
Key features	Precision writing	Handwriting mimicking technology
	Multilingual support	Processes/responses in English, French, Arabic, and Spanish.
	Dynamic Interactions	XPEN “Eyes” and “jump” features.
	Privacy-Oriented Design	Camera/microphone disabled by default, manual toggles for user control.
Physical design	Size	4.7 x 3.1 x 3.2 inches (latest prototype).
	Display	4-inch touchscreen (480x800)
	Cooling system	Passive system
	Power Source	USB-C for charging only (27w / 12V 2.25A)

Power & Connectivity	Battery	(still not implemented) 4865mAh at 11.1V, providing ~2 hours of runtime with XPEN's 27W power consumption.
	Ports	2x USB-C ports for data/document imports; 1x 3.5mm jack for audio.

VI. What's next?

We are working hard to make XPEN everything it needs to be, turning it into a final, market-ready prototype that includes all of the features we have envisioned. That includes smart calligraphy for creative scripts, handwriting precision tailored to different languages, and advanced accessibility tools that ensure XPEN truly works for everyone, particularly those with disabilities.

Portability is also a priority, so we are adding a rechargeable battery to make XPEN more portable. We are also developing a companion app that will sync notes, recordings, and summaries across devices. We also intend to open up XPEN's APIs so that developers can create custom add-ons, further improving XPEN's capabilities.

Global language support is also important, which is why we intend to add support for 13 other languages. At the same time, we are working on fee waivers and subsidized programs to ensure that students who need them most will not be prevented from having one.

Ultimately, our goal is to create an adaptable and inclusive device, capable of changing the way people learn and interact with technology.

VII. Credits

- **Mom and Dad**, thank you for enduring our noisy sleepless nights, believing in our ideas, and patience through our countless experiments.
- **Bilal Mohamed Rayan**, my co-founder, thank you for your brilliance in software development, engagement, and team spirit, which made this project possible.
- **Didier Tranchier**, our mentor, with his signature "Too much tech, not enough profit," thank you for guiding us on scalability, design, and strategy.
- **Abdelali Belghiti**, the investor who first believed in XPEN, thank you for your support with both resources and trust in our vision.
- **Elafia Mounsif**, head of the patent department, thank you for your ongoing support and expertise in navigating the patent process.
- **Open-Source Contributors**, a heartfelt thank you to the incredible developers behind Buildroot, TensorFlow, OpenAI APIs, and Google APIs. Your tools were the foundation of XPEN's innovations.

I thank everyone who contributed, guided, or simply believed in this journey, as XPEN is as much a reflection of their support as it is of our work.