Bloomy: A Robotic Flower for Intuitive Air Quality Monitoring

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***Abstract*—Asthma is a chronic respiratory condition that affects millions worldwide, with symptoms often triggered by poor indoor air quality. Despite the health risks posed by pollutants such as PM2.5 and CO_2, existing monitoring systems often rely on passive digital interfaces that require users to interpret graphs or numerical indicators—barriers that limit real-time awareness and action. In response, we present Bloomy, a robotic flower that functions as an intuitive, ambient air quality companion. Bloomy expresses environmental conditions through tangible feedback—blooming or closing its petals and changing LED colors based on sensor data—offering an emotionally resonant alternative to traditional displays.**

Our system combines real-time sensing, wireless communication, and expressive actuation using a custom-designed rack-and-pinion mechanism driven by a stepper motor. We describe our iterative design and fabrication process, including the integration of NeoPixels, microcontrollers, and 3D-printed components within a lotus-inspired form factor. We also detail challenges related to power constraints, mechanical tolerances, and system-level integration, and share lessons learned from prototyping and user feedback.

Bloomy demonstrates the feasibility and appeal of tangible interfaces for health-related monitoring, especially in the context of asthma awareness. It transforms invisible environmental risks into visible, glanceable feedback and serves as a foundation for future work in ambient, emotionally engaging health technologies.

I. Introduction

Asthma is a prevalent health concern, with the Centers for Disease Control and Prevention estimating that 1 in 13 Americans suffer from the condition. Episodes are often triggered by poor air quality, particularly indoor pollutants such as volatile organic compounds (VOCs), carbon dioxide (CO_2), and fine particulate matter (PM2.5). While numerous digital tools exist to monitor air quality, many require active checking of apps or interpretation of complex visualizations—barriers that often reduce sustained engagement and real-time action.

Studies have shown that users benefit from glanceable and tangible representations of data, which lower the cognitive barrier to awareness and prompt more immediate behavioral responses [3], [5]. Inspired by this, we designed Bloomy: a robotic flower that communicates air quality through simple, universally understood metaphors—color and blooming. The flower opens and glows green when air is clean, partially closes and glows yellow when conditions are moderate, and fully closes with a red alert when poor air quality is detected. These states map clearly to a user's mental model of environmental health, requiring no technical background or explicit data interpretation.

Our goals with Bloomy were threefold: (1) to create a fully functional and responsive environmental sensing system, (2) to translate complex air quality data into emotionally engaging physical output, and (3) to develop a solution that is aesthetically pleasing and suitable for home environments. In what follows, we describe our end-to-end process—from component selection and prototyping to BLE-based communication and feedback logic—alongside challenges, iterations, and final insights. We hope Bloomy provides both a technical and experiential contribution to the field of ambient and tangible computing.

II. Related Work

Commercial and academic systems have long explored how to represent environmental data to end users, but most rely heavily on numeric or graphical outputs, which can be cognitively demanding or easily ignored.

Products like the Atmotube PRO [2] provide highly accurate real-time environmental data but present it in a format that requires users to engage with a mobile app to make sense of the information. This introduces friction in everyday use and limits the ability for users to respond quickly to changing conditions. Even with push notifications, the abstract nature of numerical scores or air quality indices requires interpretation that may not be intuitive to all users, especially children or the elderly.

The inAir studies by Kim and Paulos [3], [4] aimed to address this challenge by introducing ambient visualizations of indoor air quality. Their work demonstrated that even simple graphs shown in the periphery of a user's environment could improve awareness. However, these systems still required users to observe and decode visual patterns and lacked physical interactivity or emotional engagement. Our project builds on this notion by translating air quality into expressive physical behaviors that can be observed at a glance and felt intuitively.

Further, studies such as those by Wong-Parodi et al. [5] and Zhou and Sampath [6] show that users respond more positively and take more proactive health actions when environmental feedback is tangible, immediate, and embedded within their living space. Devices that integrate sensing and feedback into a unified and meaningful physical artifact have been shown to increase trust and adoption rates, particularly in health-sensitive contexts like asthma care.

Bloomy distinguishes itself from prior work by combining air quality sensing with expressive, flower-like motion and light, fostering a calming yet informative experience. It draws inspiration from calm technology and tangible user interfaces, creating a seamless blend of functionality and emotion. By focusing on natural metaphors like blooming and wilting, our design leverages embodied cognition to make invisible phenomena like air pollution feel more real, accessible, and actionable.

III. Design Goals and Assumptions

Our design emphasizes tangibility and simplicity, aiming to communicate air quality in an intuitive and non-intrusive way. The physical form prioritizes high visibility, designed to be seen clearly from across a room. For example, the device may bloom or wilt like a flower, providing an immediate visual metaphor for good or poor air quality, respectively.

We also wanted the device to serve as an aesthetically pleasing, decorative object that fits naturally into a home environment. Since air quality typically does not change frequently, the device is designed to blend into the background when conditions are normal, and gently capture attention when something changes, functioning both as a passive sculpture and an active alert system.

We operate under the assumption that users can interpret metaphorical cues, such as associating a wilting flower with poor air quality, or interpreting unnatural flower colors (e.g., bright blue, orange, or red) as signs of abnormality, and pink as an indicator of clean air. These metaphors are chosen for their emotional resonance and universal familiarity.

While the primary audience includes individuals with asthma and their caregivers, who benefit from clear, ambient cues without needing to check digital displays, the device is also intended to appeal to anyone interested in monitoring their air quality through a functional yet beautiful object in their living space.

IV. System Overview

This system combines environmental sensing, metaphor-driven actuation, and ambient feedback to create an intuitive air quality monitor. The design integrates both hardware and software components to produce a responsive, visible, and decorative object.

A. Hardware Components

Detailed Components: **Sensors:** The system uses a suite of environmental sensors to monitor indoor air quality:

- **Adafruit PMSA003I:** Measures PM2.5 and PM10 particulate matter to detect airborne pollutants.
- **Adafruit SCD-40:** Measures carbon dioxide (CO_2) concentration to assess ventilation and air freshness.

Actuators:

- **Stepper Motor:** Controls the mechanical blooming and wilting of flower petals, serving as a tangible metaphor for air quality conditions.
- **NeoPixel Ring:** Provides color-based visual feedback, using metaphorical color cues (e.g., pink = good, red/orange/blue = poor) to convey air quality at a glance.

Controller:

- **CLUE:** Acts as the sensor hub. It reads data from connected sensors (PM2.5, CO_2), runs air quality evaluation logic, and communicates the results via Bluetooth.
- **Feather nRF52840:** Serves as the main controller and Bluetooth receiver. It receives air quality status messages from the CLUE via Bluetooth and executes the appropriate logic to control actuators. It is stacked directly on the CRICKIT FeatherWing, allowing it to command the attached hardware.
- **CRICKIT FeatherWing:** Functions as the actuator driver board, connected to and controlled by the Feather. It interfaces with the NeoPixel (for color feedback) and stepper motor (for petal movement), executing commands passed from the Feather.

B. Software Pipeline

Sensor Data Acquisition: Periodically collects data from all sensors to capture current environmental conditions.

Threshold-Based Logic: Processes raw sensor inputs and compares them against predefined thresholds to determine air quality status for both CO_2 levels and particulate matter (PM2.5/PM10).

Communication & Feedback Display:

- The Adafruit CLUE transmits the computed air quality status via Bluetooth to the Feather nRF52840, which handles actuator control.
- Detailed sensor metrics and air quality state are also displayed on the CLUE's onboard screen, offering real-time feedback for users seeking more granular insight.

Actuator Control: Based on the current and previous air quality states:

- The stepper motor opens or closes the petals to metaphorically represent air quality as a blooming or wilting flower.
- The NeoPixel ring updates its color to reflect severity levels, providing ambient visual cues (e.g., pink = good, red/orange/blue = poor).

V. Fabrication and Prototyping Process

Sensor Part

This component is responsible for sensing indoor air quality and transmitting the information to the output system. We used the Adafruit PMSA003I to measure PM2.5 and PM10 particulate matter, and the Adafruit SCD-40 to measure CO_2 levels. These sensors were connected to the Adafruit CLUE board, which serves as the data collection and Bluetooth transmission unit.

Code Resources:

- Full project code: https://github.com/olivesmoo/bloomy
- Component testing: https://github.com/olivesmoo/bloomy/tree/6ee4889514b704a9ca89f710762d021b81b8aec5

Output Part: Physical Prototype

We initially explored a tulip-based design, but its upright and fragile structure was not mechanically reliable. We pivoted to a lotus-inspired form where the stem remains hidden, enabling better stability and mechanical motion.

Design Concept and Mechanism:

The blooming mechanism was modeled in Tinkercad and implemented using a rack-and-pinion system. A stepper motor drives the gear (pinion), which translates rotation into vertical linear motion to actuate the petals.

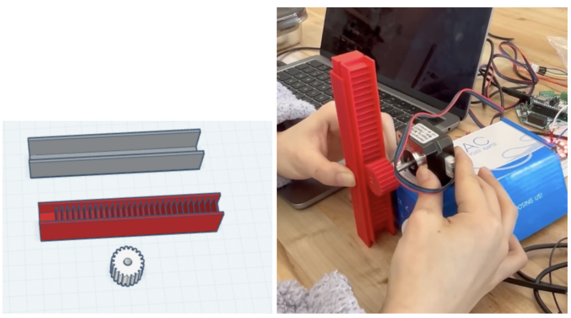

Fig. 1. Rack and pinion CAD model (left) and stepper motor test with rack prototype (right)

While the first 3D-printed prototype was successful in terms of structure, some smaller elements lacked precision. These tolerances prevented smooth blooming, leading us to iterate on the design and explore alternative 3D models, including a pre-designed lotus flower form.

Mechanical Improvements:

- Added cable passthrough holes for NeoPixel wiring.
- Designed stem-to-motor couplings to prevent slippage.
- Introduced a weighted, stationary vase to avoid full assembly rotation.

Final Assembly

The final prototype integrates the flower, electronics, and structure into a single expressive unit. The NeoPixel sits at the center of the flower and changes color based on air quality levels. The stepper motor drives blooming/wilting via vertical motion, coordinated through Bluetooth communication.

Electronics and Control Logic

We used the Feather nRF52840 microcontroller and Crickit FeatherWing to control the actuators. The control system listens for Bluetooth messages from the CLUE board and responds based on sensor data.

Behavioral Logic:

- Default flower state is closed.
- If air quality is good:

Fig. 2. Bloomy prototype in different bloom states with multicolor LED feedback

  - LED turns pink.
  - Motor activates to bloom.
- If poor conditions are detected:
  - LED changes to yellow (PM2.5), blue (CO_2), or red (both).
  - If previously open, flower closes.

Power Management: To reduce power load and thermal strain, the system disables the stepper motor after 40 seconds and inserts a sleep period before the next actuation cycle.

This design and fabrication process exemplifies the iterative development required to merge aesthetics, motion, and sensor feedback into a tangible, expressive interaction.

VI. Evaluation

Functional Tests of Each Sensor

We conducted individual functional tests for each sensor to verify accurate data transmission and responsiveness. The Bluetooth-connected air quality sensor was evaluated under a variety of environmental conditions to observe how it responded to changes in PM2.5 and CO_2 levels.

For example, in the MakerLab, where many physical components are being actively cut, sanded, and assembled, the sensor consistently reported elevated PM2.5 levels. This result aligned with expectations, given the abundance of particulate matter in the space. In another test, we placed the sensor in a small, enclosed room with four people present. The CO_2 readings increased significantly, reflecting reduced air circulation and increased carbon dioxide from human respiration. Additionally, we performed a controlled test by manually exhaling onto the sensor.

Petal Movement Responsiveness to Thresholds

The blooming and closing motions of the flower were directly tied to real-time air quality thresholds. When the sensor detected favorable conditions, the stepper motor reliably actuated the blooming mechanism, and the NeoPixel ring shifted to a soft pink hue, signaling clean air. Conversely, when poor air quality was detected, such as elevated PM2.5 or CO_2 levels, the flower retracted, and the LED color changed accordingly to reflect the specific pollutant.

While the system generally responded as intended, it occasionally encountered mechanical issues due to power limitations. Specifically, when both the stepper motor and the LED ring were active simultaneously, the motor sometimes failed to complete its full rotation. This incomplete actuation resulted in the flower not fully opening or closing. These power-related issues will be discussed further in the *Challenges* section.

VII. Challenges and Lessons Learned

Mechanical Noise

One unexpected challenge was the noise produced by the stepper motor during operation. While the motor performed reliably in terms of actuation, the mechanical sound generated—particularly during the blooming and closing actions—was noticeably loud. This detracted from the intended calming and organic aesthetic of the flower, which was designed to subtly reflect environmental quality in a home setting. Future versions may explore quieter motor alternatives or dampening techniques to preserve the ambient nature of the device.

Power Constraints and Actuation Reliability

Another significant challenge was the power distribution between the stepper motor and the NeoPixel LED ring. Both components demand relatively high and stable current. When operated simultaneously, we observed intermittent performance issues, including incomplete rotations of the stepper motor and erratic LED behavior. The motor, in particular, would sometimes stall or fail to complete the blooming cycle, resulting in partially open or stuck petals.

To mitigate this, we implemented a cooldown strategy: after every actuation, the motor is released and given a rest period before the next command is issued. While this improved reliability slightly, it did not eliminate the problem entirely. These symptoms suggest that a more robust power management strategy—such as separate power sources or capacitor buffering—may be required in future iterations.

Integration Complexity

Although each subsystem—the sensors, LED ring, and motor—functioned correctly in isolation, integrating them revealed unforeseen interactions. Most issues stemmed from shared power constraints, timing mismatches, and communication delays over Bluetooth. This highlighted a key lesson: individual component success does not equate to system-level reliability. Designing for integration from the beginning, including thorough system-level testing and mocking communication flows, would have mitigated some of these issues earlier in the process.

Other Implementation Issues

Beyond the core technical challenges, we also faced mechanical design constraints. The routing of wires through the stem, maintaining structural stability, and aligning the servo with the flower mechanism required multiple redesigns and reprints. Furthermore, limited access to high-resolution 3D printing impacted the precision of delicate parts, occasionally causing assembly misalignments.

Reflections and Validations

Despite the above difficulties, our foundational design assumptions were largely validated. Bloomy's core metaphor—using expressive motion and ambient lighting to communicate air quality—proved to be both feasible and engaging. The metaphor of a blooming flower for clean air and wilting for poor conditions resonated with users during informal demonstrations, reinforcing our belief in the value of tangible, ambient feedback for health-related awareness.

These experiences taught us the importance of designing with both emotional resonance and technical feasibility in mind. Our work supports the idea that tangible computing systems, when carefully integrated, can provide accessible and meaningful interaction paradigms for sensitive domains such as asthma management.

VIII. Conclusion

Bloomy transforms air quality monitoring into a gentle, beautiful interaction. Rather than relying on numeric data, mobile notifications, or app-based graphs, it leverages tangible metaphors—light and motion—to intuitively alert users to changes in their environment. By blooming in clean air and wilting in poor conditions, Bloomy reduces the cognitive load typically associated with interpreting environmental data, making it especially accessible for asthma sufferers, children, and the elderly.

Our prototype demonstrates that ambient, emotionally resonant feedback can increase engagement and promote proactive behavior without requiring constant user attention. The seamless integration of sensors, wireless communication, and expressive actuation bridges the gap between utility and aesthetics—making health-relevant information feel natural, visible, and meaningful in a home context.

Despite technical hurdles such as mechanical noise, power distribution issues, and integration complexity, the core design metaphor proved both functional and effective. Our evaluation suggests that Bloomy's flower-like behavior is not only legible to users but also appreciated as an emotionally expressive companion. The process reaffirmed that early system-level testing and iterative prototyping are crucial in developing tangible, interactive systems.

Looking ahead, Bloomy lays the groundwork for future health-monitoring devices that are ambient, decorative, and emotionally aware. Future iterations may include quieter actuation, adaptive behavior based on user habits, multi-sensor fusion for broader environmental insight, and long-term deployment studies to evaluate behavioral impact. We believe Bloomy's principles can inspire a new generation of tangible interfaces that democratize access to environmental awareness and transform how we experience and respond to invisible health risks in our everyday spaces.

Authorship and Contributions

All group members contributed significantly to the conceptual development, prototyping, and writing of this report. While we collaborated closely throughout the project, each member also took primary responsibility for specific aspects to ensure a balanced and efficient workflow.

- **Yuval Steimberg** led the hardware integration and sensor system development, and contributed heavily to the evaluation and fabrication sections of the report.
- **Helenna Yin** focused on the mechanical design and prototyping of the blooming mechanism, including the CAD modeling and 3D printing process, and authored the fabrication and design goal sections.
- **Olivia Mei** worked on the code logic for Bluetooth communication and actuator control, and contributed to the implementation and system logic portions of the write-up.
- **Nana Takada** contributed to user experience considerations and visual design, and led the writing and editing of the introduction, abstract, and conclusion, also worked on the code logic for Bluetooth communication and actuator control.

The related work section and final report editing were completed collaboratively. We ensured that each team member had a meaningful role in both the technical development and documentation of Bloomy.

Fig. 3. Bloomy prototype displaying its response to good air quality

References

[1] California Air Resources Board, "Air pollution and respiratory health." [Online]. Available: http://www.arb.ca.gov/

[2] Atmotube PRO. [Online]. Available: https://atmotube.com/atmotube-pro

[3] S. Kim and E. Paulos, "inAir: Measuring and visualizing indoor air quality," in *Proc. Ubicomp*, 2009.

[4] S. Kim and E. Paulos, "InAir: Sharing indoor air quality measurements and visualizations," in *Proc. CHI*, 2010.

[5] G. Wong-Parodi, M. B. Dias, and M. Taylor, "Effect of using an indoor air quality sensor on perceptions...," *JMIR mHealth and uHealth*, vol. 6, no. 3, 2018.

[6] X. Zhou and V. Sampath, "Effect of air pollution on asthma," *Annals of Allergy, Asthma & Immunology*, vol. 132, no. 2, 2024.