GadJets: Exploring Air-Jet-Actuated Passive Materials and Mechanisms for Actuated and Shape-Changing Interfaces

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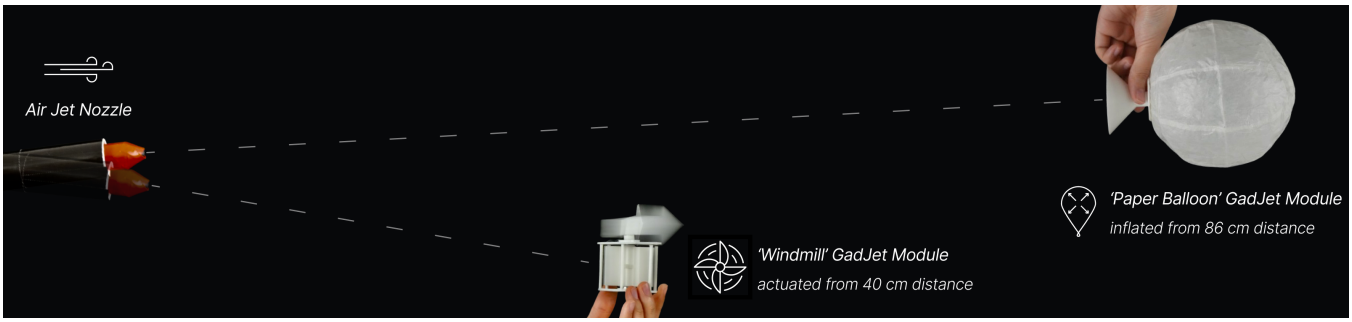


Figure 1: GadJets: Air jet nozzle may actuate "windmill" GadJet module from 40-cm distance, and inflate "paper balloon" GadJet module from 86-cm distance.

ABSTRACT

We propose GadJets, an approach to remotely actuating passive materials and mechanisms using air jets for interactive and shape-changing tangible user interfaces (TUIs). Compared to previous HCI research in remote actuation, air jets offer relatively strong, distant, and safe actuation with simple control. Leveraging these advantages, we can selectively actuate multiple passive materials and mechanisms (or GadJet modules) using only one actuator. We defined a design space to outline the basic architecture and generalizable primitives for air-jet-based TUIs. Also, we exemplified our approach with diverse GadJets modules and proof-of-concept implementation of a computer-controlled air jet system. Finally, we developed a visualization system of the estimated air range based on pre-collected data to support user control. With the vision of deploying multiple passive GadJet modules in an environment fused with the actuated air jets, we demonstrated applications of interactive tabletop objects, an actuated workbench, and an actuated shelf.

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CCS CONCEPTS

• **Human-centered computing** → **Interaction design process and methods**.

KEYWORDS

interactive material, air jet, untethered actuation

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1 INTRODUCTION

From windmills to Japanese paper balloons — air-activated toys, or *gadgets* of our childhood, have provided us with unique, magical mind-*blowing* experiences, by making movements or shape-changing behaviors simply by blowing air into them without direct contact. Air, as a driving force, has the potential to serve as a powerful medium for remotely actuating passive materials and mechanisms.

Particularly, air jets—compressed, condensed streams emitted from a nozzle—can deliver strong air currents over long distances

in a safe and simple manner. Compared to other air delivery methods, such as fans, air jets are notably stronger and more precise with focused air. Thanks to these characteristics, air jets have been employed in haptic research to achieve non-contact, strong, and instant force feedback [27, 28, 35]. On the contrary, our paper focuses on another unexplored capability of air jets, i.e., selective, reconfigurable, non-contact actuation of passive materials and mechanisms for interactive, shape-changing, and actuated tangible user interfaces (TUIs).

Previous research in Human-Computer Interaction (HCI) has explored the remote, non-contact actuation of passive objects and materials using magnetic forces [3, 11], ultrasonic acoustic levitation [20, 21], lasers [10], continuous airflow [1, 39], and so on. However, these methods often face limitations such as restricted distance ([11, 20]), relatively weak force of actuation (lifting 1.2 g polystyrene balls in [39] and similarly lightweight polystyrene balls in [1]), concerns about safety [10], and complex control requirements. In contrast, air-jet-based actuation offers relatively strong, distant, safe, and simple control through bursts of high-velocity air for activating passive mechanisms and materials, which remain largely unexplored in the HCI domain.

To this end, this paper introduces a method to computationally control air jets to actuate passive materials and mechanisms, which we define as GadJet modules (Figure 1). By harnessing the air jets, we can keep the GadJet modules passive, electronics- and battery-free. Therefore, the approach of GadJet aims to add a novel non-contact actuation method within the realm of HCI, specifically in interactive, programmable responsive material research [2, 14, 16, 33, 36].

To explore this novel approach, we define a design space for GadJets, which lays out the basic architecture and primitive design elements for the GadJets modules. This includes how GadJet modules should be structured (e.g., air receiver, inflatable, windmill, one-way valve). Our proof-of-concept implementation demonstrates this design space through computationally controlled air jets, based on a system consisting of an air compressor (70 psi), nozzles, and an electric valve, to actuate custom-designed GadJet modules with diverse functionalities. The hardware system is further supported by the software system that can track the object positions and actuate them via air jet from a distance, employing a servo or an XY Plotter for nozzle base control. The GUI software also visualizes nozzle air range based on pre-collected data (see 4.1 for details), displaying the region that air jets would reach, to help the user easily plan and control the nozzle to actuate target modules and avoid blowing out objects or modules inattentively. With the hardware and software system, we introduce a generalizable workflow.

We then present the applications that demonstrate the potential of GadJets for interaction design scenarios, including tabletop TUIs for gaming and work assistance, actuated shelves, and point-to-actuate room environments. The applications project a unique vision for future environments where a single (or a few) computationally controlled air jets are embedded in environments, selectively and reconfigurably actuating diverse passive materials and mechanisms to provide rich and diverse tangible interaction. We lastly discuss the limitations and challenges of employing our approach, which we found through our prototypes and experimentation. Overall, the approach of GadJets contributes to HCI by leveraging air jets as a new medium to actuate passive materials and mechanisms from a distance for shape-changing and actuated TUIs.

The contributions of this paper are:

- an approach to use air jets to actuate passive materials and mechanisms (GadJet modules) from a distance;
- a design space that outlines an overall architecture of actuated air jets and passive modules, and primitive elements for the modules' design to support diverse actuation;
- a proof-of-concept implementation and a generalizable workflow of data collection for enhanced air jet targeting, and a technical evaluation of the system;
- application examples that exemplify how the approach can enrich future interaction with tangible objects and physical environments.
- a discussion of challenges and limitations for the approach of GadJets

2 RELATED WORK

2.1 Non-Contact Actuation of Passive Objects

HCI researchers have explored different actuation methods on passive objects to enhance their interactivity. Besides the straightforward method to manipulate passive objects and modules "in contact" with actuated devices [4, 26, 32], there is a growing body of research on 'non-contact' actuation. Various technical approaches have been investigated within this realm. For example, acoustic levitation has been actively developed to actuate small particles in mid-air [7, 20–22, 25], which are unique in precisely controlling a number of small particles in 3D, while it is limited to light objects over relatively small distances. Magnetic force is also actively employed to actuate objects from under-table surfaces, as in Actuated Workbench [24], or used to levitate a sphere in mid-air, as in ZeroN [11]. Laser has been proposed to heat shape memory alloy with precise focus and targeting to induce bending actuation (Animated paper [10]), though there is a safety concern of using laser beams. Researchers also used air to actuate passive objects. For example, floatio [39] and Aerial Tunes [1] used continuous airflow for stable object levitation. On the contrary, our focus, air jets, different from continuous airflow, offer strong bursting forces. Prior works in robotics explored the 2D translation of a cylindrical object by air jets [8]. However, few have explored harnessing air jets to actuate passive mechanisms and materials for interaction.

In summary, existing non-contact actuation systems have different pros and cons for actuating passive materials and objects. While Air Jet also has shortcomings such as noise and difficulty with precision, delicate control, and loss of energy (further elaborated in 7), it features advantages in relatively safe, simple control (just aim-and-shoot), and instant, strong actuation (with bursting force). This paper explores the possibility of this new actuation method to control the movement and shape of passive mechanisms, and its method.

2.2 Reconfigurably Actuating Passive Modules

HCI researchers have developed interactive systems by combining reconfigurable passive modules with active machines to enhance interactivity. For example, HERMITS [16] employs two-wheeled

robots to activate various passive shell add-ons, defined as "mechanical shells" [15]. TRANS-DOCK [17], Kinetic Blocks [26], and AnimaStage [18] use pin-based displays as actuators for passive objects such as paper crafts, blocks, and passive transducers. MagneDot [30] introduced a method to fabricate passive, silicone-based, ferromagnetic materials to be controlled by a magnetic field beneath the surfaces. In Dynablock [31], passive magnetic blocks were combined with an active display to create and recreate 3D shapes instantly, while Elevate [9] introduced a unique shape display design composed of passive pins with locking mechanisms, and an actuated mechanism to refresh the pin heights to achieve a large-scale actuated surface.

While existing research has primarily focused on methods that rely on physical contact, we take the first step in employing air jets to actuate passive modules. Leveraging air jet uniquely contributes to this realm of research in reconfigurably actuating passive mechanisms, where computationally controlled jet air can selectively actuate them.

2.3 Air-Jet-Based Haptics

Many researchers in HCI have explored air jets for creating haptic feedback from a distance without direct contact because of their ability to exert a strong and instant force remotely. One way to create haptic feedback is to hit the human body with air jets directly. For instance, HAIR [35] embeds nozzles in the environment and shoots air jets to provide haptic feedback without requiring the user to hold or wear any devices. AIREAL [29] uses an air vortex (a type of air jet) for creating haptic feedback up to 1 m. Another way to create haptic feedback is to create propulsion by shooting air jets into mid-air. Some researchers mounted nozzles on wearable devices such as smartwatches (Jetto [5]) or head-mounted displays (HeadBlaster [12]) to create haptics, while others mounted nozzles onto the controllers to create haptics (AirRacket [34], JetController [37]).

A large body of previous air-jet-based systems in HCI has focused on conveying haptic feedback to users directly. In contrast, we expand on the air jets' usage by enhancing it with passive materials and mechanisms, such as inflatables and windmills.

2.4 Inflatables for Shape-Changing Interfaces

Inspired by soft robotics research, HCI researchers have employed pneumatic actuation for shape-changing interfaces [38]. Various techniques and material structures for inflatables have been explored, such as planar pneumatic actuators as in aeroMorph [23], milliMorph [13]. However, conventional pneumatics are known for several primary technical difficulties. One major issue is air leakage, which researchers and developers often suffer from, as ensuring air-tight connections is essential to maintaining pressure. Additionally, these inflatables often require tethered tubes connected to the air source for continuous air supply, which limits the mobility and practicality of conventional pneumatic systems in more dynamic applications.

In soft robotics, some studies have successfully developed untethered pneumatic shape-changing interfaces, for example, by embedding phase-changing liquid into inflatable pouches (Liquid Pouch Motors [19] and Laser Pouch Motors [6]). While these methods were able to embed the "actuation source" within the pouch, our approach decouples the actuation source from the materials, where the materials are actuated from a distance by air jets. This separation opens up new possibilities for reconfigurable interactive scenarios and offers much stronger actuation energy to be conveyed to the passive materials compared to the "pouch motor" approaches in soft robotics.

3 GADJETS DESIGN AND HARDWARE IMPLEMENTATION

Figure 2 illustrates the design space of GadJets, highlighting the overall architecture and passive module design. These are presented as open-ended explorations, offering example configurations and designs for jet-based actuated materials and mechanisms, rather than a complete or exhaustive list. This design space serves as a starting point for future research on jet-air actuated interactive matter.

3.1 Basic Architecture

GadJets is grounded in the principle of enabling selective, reconfigurable, untethered actuation for passive materials and mechanisms using controlled air jets. To realize this, we focused on three key principles: (1) designing passive modules that convert directed air jets into motion without embedded actuators or pneumatic tubing; (2) enabling directional and selective actuation through varied air sources and nozzle geometries; and (3) enabling selective actuation by repositioning the air source point through controllable nozzle bases.

These principles informed the basic architecture of our system, consisting of the following key components: *GadJet modules*, *a nozzle*, *an optional nozzle base*, and *an air source* (Figure 2 upper left). The core idea is to use a single (or a few) nozzle(s) to actuate one or multiple passive GadJet modules, optionally supported by nozzle bases that allow for 1-3 degrees of freedom (DoF) nozzle movements. GadJet modules can be placed on a variety of surfaces, such as a tabletop, shelves, and walls, and can be actuated by directing air jets from a distance. We explored design variations for each key component to support different configurations and use cases, which we elaborate on in the following sections.

3.2 GadJet Modules

GadJet Modules are central to our approach. Each module comprises: 1) an air receiver, which guides incoming air jets to motion, and 2) a core motion primitive, which generates visible movement (Figure 2 upper right). We focus on two types of motion primitives- *inflatable* and *rotational*— both widely used in shape-changing interfaces as basic movements, achieved by air jets. We developed a library of such modules with varied configurations; representative examples include paper balloons and windmills. To prevent modules from being displaced by the force of air jets, we secure them with weights or adhesives (e.g, magnets).

Below, we detail the core motion primitives employed in GadJet modules. The 3D models (.stl files and parametric Fusion 360 files) for our GadJet modules are open-sourced for fellow researchers and designers [1].

[1] https://github.com/AxLab-UofC/GadJets

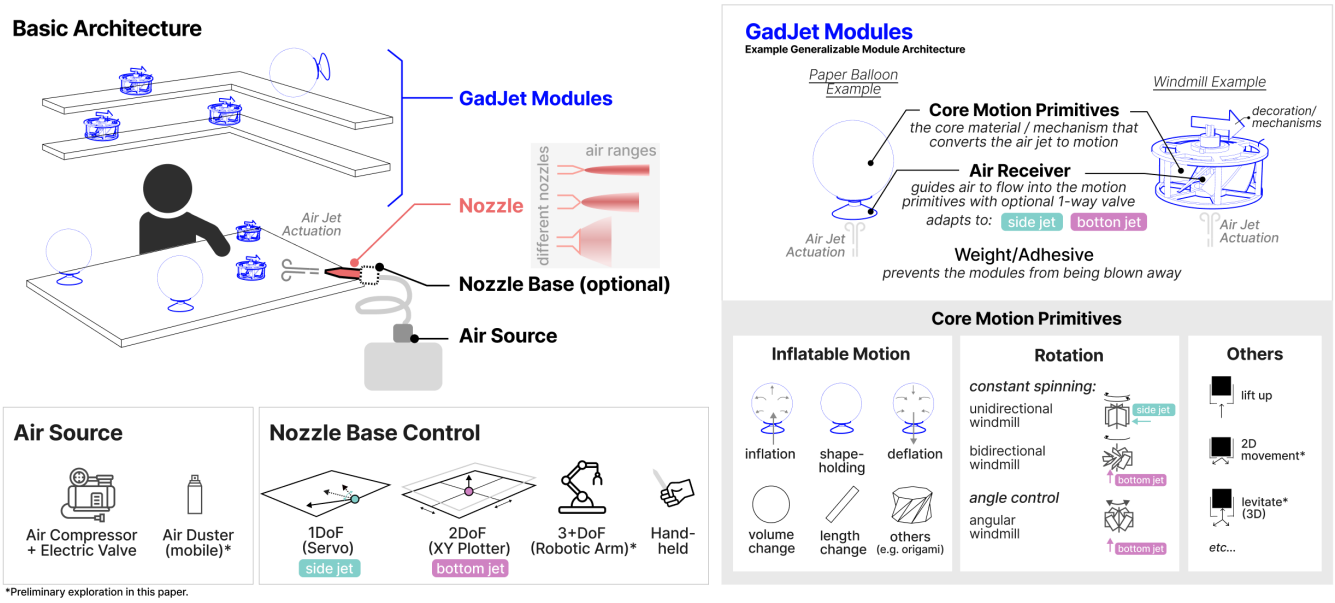


Figure 2: Design space of GadJets.

Inflatable Motion: Directed air jets can be harnessed to induce shape change in inflatable structures. In particular, unlike common pneumatic systems, our system can achieve inflation and deflation untethered. This facilitates selective actuation without requiring tethered airflow or airtight connections. We did this by designing a custom openable one-way valve (Figure 3)[2]. By attaching our custom openable one-way valve to common elastic inflatables such as rubber balloons, we can achieve untethered inflation/deflation by simply targeting the air jets at different areas of the valve.

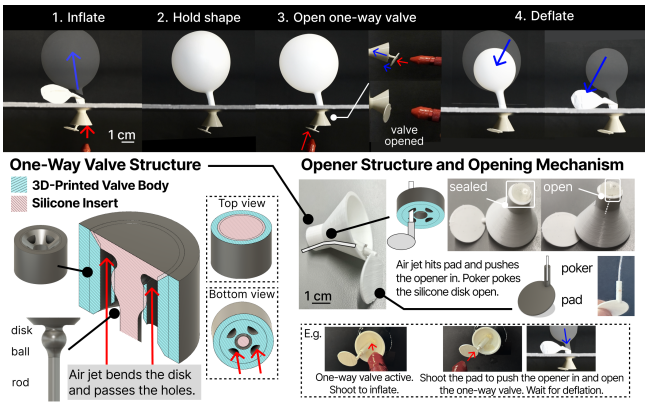


Figure 3: *top.* Latex balloon with an openable one-way valve inflated and deflated by air jets. *bottom.* One-way valve structure and opening mechanism explained.

We also explored materials with inherent physical properties — specifically, shape-holding and shape-reversing behavior. For the former, we used glassine paper, a semi-transparent material that retains its shape after inflation. Using this, we created lightweight paper balloons as inflatable structures (Figure 4a). For shape-reversing, we employed a commercially available length-changing inflatable equipped with an internal elastic wire, which automatically retracts the structure after extension (Figure 4b).

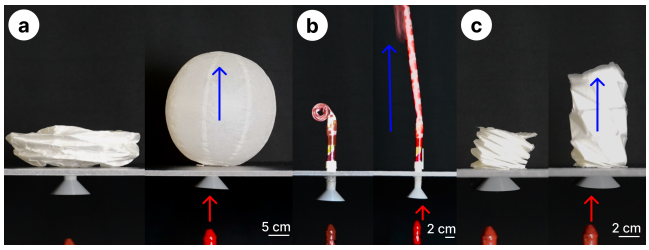


Figure 4: Inflatable primitives. a) Volume change b) Length change c) Other mechanisms, such as kresling origami

Overall, depending on the shape and structure of the inflatable, the GadJet modules support volume change, length change, or other complex shape-changes using origami structures (Figure 4c), which we will demonstrate in later applications.

Rotation: Rotation is another basic motion primitive in our system. We designed different types of windmills to enable two modes of rotational motion: constant spinning and angle control. Constant spinning can be achieved both from the side or bottom, using unidirectional or bidirectional windmills in Figure 5, respectively. Depending on the air jet's direction, the windmill can rotate bi-directionally with the side jet.

Air jets can achieve precise angle control using our angular windmill, which features an opposite yet symmetrical blade pattern

[2]inspired by https://www.instructables.com/3D-Printed-Check-Valve/

(Figure 5 right). Due to this symmetry, the windmill naturally stabilizes at an equilibrium position when the air jets are applied. As the air jet shifts position, the windmill rotates left or right accordingly, maintaining a stable and controlled movement.

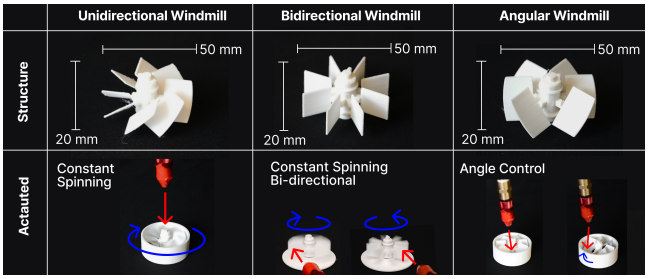


Figure 5: Windmill primitives: unidirectional windmill, bidirectional windmill, angular windmill.

Other Movements: Beyond inflation and rotation, objects can be lifted up and perform translational motions, guided by an air receiver. Also, air jets can be employed to move objects in 2D (explored in [8]) and levitate objects for 3D translation (explored in [39]), while they were not the focus of this paper.

3.3 Air Source and Nozzles

Air Source: The air source determines the strength and reach of the air jets, which are critical for untethered remote actuation. We prioritized sustained high-pressure output to support longer interaction sequences. Given that air jets disperse quickly in open space, we selected sources based on two key criteria: high air pressure and a tank for continuous, stable output. After comparing off-the-shelf options, we adopted a setup comprising a ROLAIR JC10PLUS air compressor (2.5 gal tank), a solenoid electric valve (up to 150 psi), and a hose (up to 120 psi) (Figure 6). We operated the compressor at 70 psi, based on empirical tests showing it provided sufficient force to actuate modules up to 1.5 meters away. Higher pressures close to the limit caused excessive noise and raised safety concerns; lower pressures led to unreliable actuation, especially for heavier or more distant modules. We also tested canned compressed air (air duster) as a mobile, electronics-free alternative. While it lacks a continuous, intense air supply, it offers portability for simpler use cases.

Nozzle: Nozzles are another key component for delivering the compressed air to the GadJet modules, and different nozzles can affect the reach and spread of the air jets, which future researchers following this approach shall pay attention to. For instance, narrow, cone-shaped nozzles produce concentrated, high-velocity air jets, while wider nozzles disperse the airflow over a broader area, resulting in weaker but more widespread jets. We define the 'air range' as the area a nozzle can reach to effectively convey air jet energy and actuate passive modules. Nozzle shape thus plays a crucial role in enabling targeted actuation. In our system, we primarily used narrow cone-shaped nozzles with a 5–7mm outlet diameter. This design provided a balance between reach (air range) and directional selectivity. We compared off-the-shelf nozzles of various shapes to measure their air ranges, detailed in subsection 4.3.

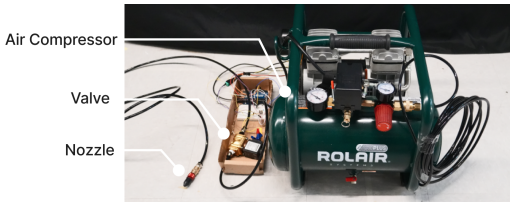


Figure 6: A picture of an air source: an air compressor connected to a nozzle via a valve.

3.4 Nozzle Base Control

To expand the actuation range and support selective actuation of the passive modules, GadJets allows optional control of the nozzle base. Several base types are possible to implement, categorized by different DoFs.

AS a *1 DoF* base, for example, a servo motor rotates the nozzle for side jets (Figure 7a shows an example implementation using MG996R), suitable for tabletop use. This configuration is compact and simple, but limited in its directional reach. For a *2 DoF* base, an XY plotter enables precise actuation near the target by moving the nozzle underneath or beside objects (Figure 7b, using [3]). Its planar mobility across horizontal or vertical surfaces ensures adaptable deployment. For a *3+ DoF* base, a robotic arm (Figure 7c) enables wide reachability, allowing the actuator to target modules across a broad area , from 3D coordinate (x,y,z) and angles (row, pitch and yaw). For our implementation, we focused on 1 and 2 DoF bases as a proof of concept prototype.

Additionally, *handheld* is another option for the nozzle base (Figure 7d), offering direct user control in a manner of a wand or pointing-device affordance, expanding the potential for embodied interaction in everyday contexts.

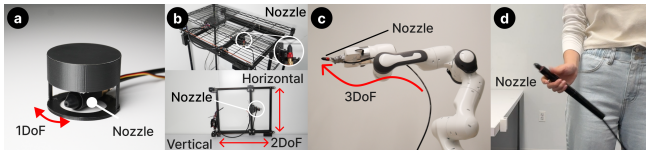


Figure 7: Nozzle base controls in GadJets. a) 1 DoF servo-controlled nozzle. b) 2 DoF nozzle mounted on an XY Plotter. c) 3+ DoF nozzle controlled by a robotic arm. d) nozzle held by hand

4 SOFTWARE PIPELINE

To help users more effectively target air jets, we developed a GUI that visualizes the nozzle air range by incorporating pre-collected airspeed data that covers a 20 cm x 100 cm region from the nozzle.

4.1 Object Tracking and Software Pipeline

We developed a software pipeline that enables users to aim and shoot objects using air jets (Figure 8). The architecture centers on Processing, which serves as the central hub for coordinating object

[3] https://www.aliexpress.us/item/3256804212627448.html

tracking, visualization, and actuation through a custom GUI. The GUI accepts object positions either from manual input or via an OptiTrack motion tracking system. This system, consisting of eight Flex13 cameras, tracks passive objects with reflective markers and sends real-time 3D position data to the GUI using OSC communication. Based on the received position, the GUI visualizes the air range and controls air jet actuation via the electric valve (24V solenoid valve), and optionally a servo motor, and/or an XY plotter. The XY plotter is controlled by Python scripts communicating with the Processing GUI via OSC, while the servo motors and solenoid valve are controlled by an Arduino receiving serial commands from Processing. By integrating the OptiTrack tracking system and the actuated nozzle base (e.g., XY plotter, a servo motor), the system supports closed-loop target and shoot air jet actuation.

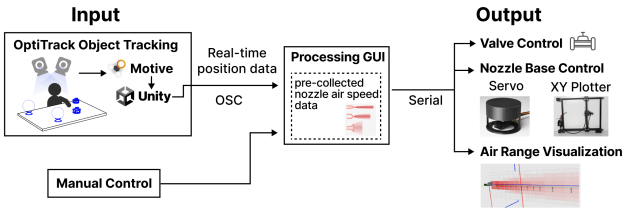


Figure 8: Software and hardware integration pipeline for air-jet-based actuation

4.2 GUI Walkthrough

We developed a GUI to control the nozzle and the air jet configuration (Figure 9).

Nozzle Control. The right-hand control panel offers fine-tuned adjustments for the nozzle system, including switching between Side and Bottom nozzle configurations, depending on the type of air jets required (side or bottom jets). Key parameters include the nozzle's XY position in centimeters, tilted angle in degrees, air jet activation (opening the nozzle), and control of the burst duration.

Targeting Mode. When tracked objects are shown, users can optionally choose among multiple targeting modes- manual, mouse click on the 2D view, or auto-following-enabling selective air jets control for both dynamic and static scenarios.

Air Range Visualization. A key feature is the red visualization of the air range based on pre-collected air speed data measured 10 cm x 100 cm region and mirrored to represent a symmetrical area (see subsection 4.3). The red gradient represents airflow intensity—darker for stronger jets—and helps users visually interpret and estimate reach and spread for targeting or avoidance.

4.3 Air Jet Speed Data Collection Workflow

To visualize the speed profiles of air jets, we conducted two experiments. The first compared the performance of different nozzles. The second investigated how the air jet spreads over distance. Both experiments were conducted under the same conditions: 70 psi pressure, 1.0 second duration, and air released via an electric valve. Air speed was measured using a handheld anemometer. At each

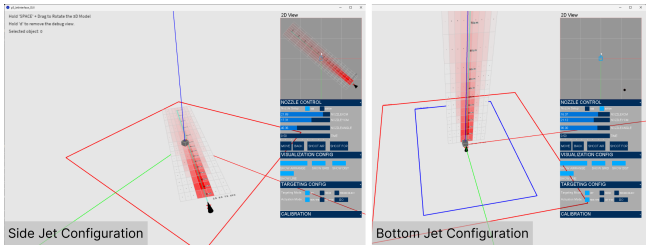


Figure 9: GUI provides both side jet and bottom jet configuration with visualizations respectively.

measurement point, we performed three trials and averaged the results. In the first experiment, we compared six nozzle designs: *long 1*, *long 2*, *normal 1*, *normal 2*, *wide*, and *omni*. Air speed was measured along the jet axis at distances from 5 to 40 cm (in 5 cm intervals up to 30 cm, and 10 cm intervals thereafter). As shown in Figure 10, the *normal 1* nozzle consistently exhibited the highest air speed, maintaining 12.53 m/s even at 40 cm. Given its superior range and directional focus, we selected the *normal 1* nozzle for further analysis in the second experiment.



unit: m/s — air jet direction →

	5 cm	10 cm	15 cm	20 cm	25 cm	30 cm	40 cm
long 1	19.61	27.62	23.72	19.14	16.01	12.95	9.9
wide	15.74	10.86	6.12	3.36	2.06	1.06	0.58
normal 1	15.93	26.41	24.22	20.63	17.72	15.05	12.53
long 2	16.85	23.17	19.85	15.74	12.42	9.57	6.64
normal 2	11.77	14.53	13.35	10.95	8.87	7.51	5.09
omni	2.68	6.1	5.08	4.33	3.68	2.82	1.58

Figure 10: Air speed (m/s) data measured along the air jet direction for six different nozzles.

In the second experiment, we tested the air flow characteristics of the *normal 1* nozzle. Air speed was measured along the jet axis from 5 to 100 cm (at 5 cm intervals up to 50 cm, and 10 cm beyond). To assess lateral spread, we additionally measured air speed at vertical offsets from 0 to 10 cm in 2.5 cm increments. We visualized the measurements of the *normal 1* nozzle, as shown in Figure 11, and used the results to inform the design of our GUI.

Our approach can be easily replicated for different conditions, including different nozzles and air compressors. By employing an air compressor set to a desired air pressure and an electric valve for controlled air release, researchers can obtain air speed distribution data under varying setups, making our approach applicable to different air-based systems or experimental contexts.

5 TECHNICAL EVALUATION

The goal of our technical evaluation is to assess different types of GadJets modules for their shape-changing, motion-enabling capabilities and to characterize the wind-guiding abilities of different air receiver parameters. Specifically, we evaluated two key GadJets modules (a paper balloon and a windmill) and various air receivers.

unit: m/s air jet direction →



	5 cm	10 cm	15 cm	20 cm	25 cm	30 cm	35 cm	40 cm	45 cm	50 cm	60 cm	70 cm	80 cm	90 cm	100 cm
0 cm	15.93	26.41	24.22	20.63	17.72	15.05	12.10	12.53	9.60	8.35	6.55	5.20	4.49	3.27	2.71
2.5 cm	15.81	18.57	15.49	14.01	12.21	11.23	8.01	7.42	6.25	5.84	4.84	3.87	3.41	2.40	2.22
5 cm	0.00	0.00	0.28	1.89	3.45	4.62	3.60	3.48	3.88	3.84	3.46	3.12	2.71	2.27	1.85
7.5 cm	0.00	0.00	0.00	0.00	0.01	0.27	0.44	1.71	1.55	1.70	2.50	2.12	2.28	1.86	1.76
10 cm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.05	0.07	0.43	0.55	0.60	0.70	0.70

Figure 11: Air speed (m/s) data measured along both the air jet direction and the vertical direction for the nozzle labeled as normal 1.

5.1 Inflation Time Test

Procedure: We mounted the paper balloon on top of a secured air nozzle and varied its distance to the nozzle, as shown in Figure 12 left. We used a paper balloon of 12 cm diameter with an air receiver attached. In our experiments, we varied two parameters: the air pressure of the air compressor (30 psi, 50 psi, 70 psi) and the distance between the nozzle and air receiver (10 cm, 20 cm, 30 cm, 40 cm). Before each test, the paper balloon was flattened and deflated. During testing, we recorded the inflation time until the balloon reached its full diameter. Each data point represents the average of five trials.

Results: As shown in Figure 12, for distances below 40 cm, it generally took below 3 seconds to fully inflate a paper balloon. The inflation time increases with distance and decreases with air jets from higher pressure. Beyond certain distances, the air jets were unable to inflate the balloon at all. Specifically, at 70 psi, the limit was 86 cm; at 50 psi, the limit was 67 cm; and at 30 psi, the limit was 54 cm.

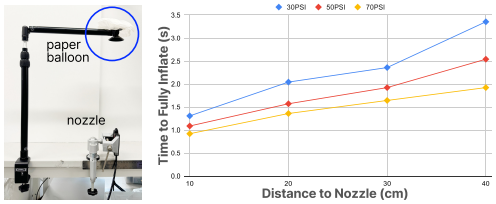


Figure 12: Time(s) to fully inflate a paper balloon at varied distances and pressure levels.

5.2 Windmill RPM Test

Procedure: We measured the speed at which our windmill modules spin under different distances and air jet conditions. We measured RPMs (revolutions per minute) of two windmill modules, both with 5 cm diameter and 8 blades but varying in height (2 cm and 4 cm tall) with a contactless tachometer (NEIKO 20713A Digital Tachometer). We show our setup and result in Figure 13. Each data point represents the average of five trials.

Results: As Figure 13 shows, air jets at 70 psi from a 10 cm distance can achieve a rotation speed exceeding 6000 RPM, surpassing the performance of an 800 KV brushless DC motor operating at 7.4 V. The graph shows that air jets from distances greater than 30 cm are ineffective at spinning the windmill used in the test. Additionally, the RPMs of the 4 cm windmill are not significantly different from those of the 2 cm windmill.

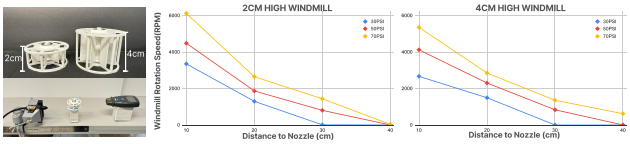
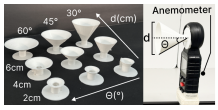


Figure 13: Windmill rotation speed (RPM) at varied distances and pressure levels.

5.3 Air Receiver Characterization

Procedure: In this section, we characterize and compare the effectiveness of air receivers guiding the air jets. We vary the diameter and angles of the receiver cones as shown on the left of Figure 14. The diameters are set at 2 cm, 4 cm, and 6 cm, while the angles are 30°, 45°, and 60°, resulting in nine different air receivers. For each air receiver, we have it 20 cm, 30 cm, and 40 cm from the nozzle to the opening of the air receiver and measure the output wind speed using an anemometer (Soonkoda). Each data point represents the average of three trials.

Results: Our results indicate that air receivers with larger diameters and narrower cone angles consistently produce air jets with higher wind speeds. This is likely because the larger diameter allows for greater air collection, while the narrower cone angle directs the airflow into a more focused stream.



Θ/d	2cm	4 cm	6 cm	Θ/d	2 cm	4 cm	6 cm	Θ/d	2 cm	4 cm	6 cm
30°	2.48	6.53	8.79	30°	2.31	5.58	7.09	30°	2.20	4.54	5.75
45°	2.60	4.93	8.62	45°	2.21	4.33	6.88	45°	2.17	3.84	5.54
60°	1.68	3.01	5.38	60°	1.72	2.37	4.28	60°	1.71	2.08	3.46
	20cm from nozzle				25cm from nozzle				30cm from nozzle		

Figure 14: Evaluation data of air receivers (with different angles and diameters) with measured wind speed at varied distances.

6 EXAMPLE CONFIGURATIONS AND POTENTIAL APPLICATION DEMONSTRATIONS

This section demonstrates example configurations and setups of GadJets, grouped based on nozzle base types, demonstrating the design space and implementation via potential applications.

6.1 Actuated Tabletop on Ordinary Tables (by placing 1 DoF nozzle base)

The first configuration presents a setup where a 1 DoF nozzle base is employed. Due to the compact mechanism, this nozzle base can be placed on an ordinary tabletop surface and actuate GadJet modules within the reach of the air jets. Figure 15 (a) presents a usage of this setup for a board game, where the system tracks the placement of the nozzle and GadJet modules with the optical marker to interactively activate the modules by 'aiming and shooting,' via the GUI (b). The system can provide versatile actuation-based functionality and expression without embedding actuators into the modules, such as an automated spinning wheel, expressive figures, and aggressively blown money (c). Both the nozzle and the modules are embedded with magnets to adhere to the game board, embedded with metal sheets.

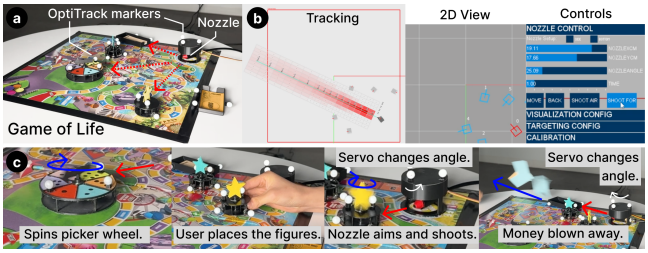


Figure 15: Actuated board game with object tracking. a) Overview. b) Tracking screen. b) Game workflow.

6.2 Actuated Tabletop and Shelves (by embedding 2 DoF nozzle base)

Employing the 2 DoF nozzle base (nozzle mounted on XY plotter), the GaJet can flexibly actuate passive modules placed in horizontal and vertical planes to be actuated.

Figure Figure 16 and Figure 17 present such examples on horizontal planes, essentially placing the 2 DoF nozzle base under a mesh or wire-based surface. Figure Figure 16 demonstrates a passive penholder embedded with GadJet's angular windmill, which can control the orientation of the holder and push out specific color pens for suggestions for the users according to their painting activity. The Whac-A-Mole game in Figure 17 is another example. Using a single nozzle, the system flexibly actuates multiple passive mechanisms to facilitate a tangible gaming experience with diverse actuated movements. Both of these examples can be facilitated with the same setup of a wire table with an X-Y plotter-based nozzle, only by placing the passive mechanism on top (without secure tubing or connection to the actuated system), which has a great potential to become a generalizable passive material actuation system.

As an example of a vertically-placed setup, we created a mock-up demonstration, placing the XY plotter in a vertical setup behind a shelf with drawers and a cabinet door (Figure 18). The system can shoot out air to push drawers out, based on the components a user is looking for (a). Using the linear inflatable mechanism, the air jet can also inflate the handle of the cabinet door — whimsically extending towards the user — to provide the dynamic affordance as guidance for the user to open the door. (b)

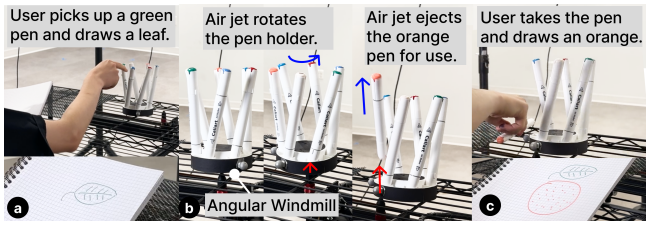


Figure 16: Actuated Workbench with object tracking

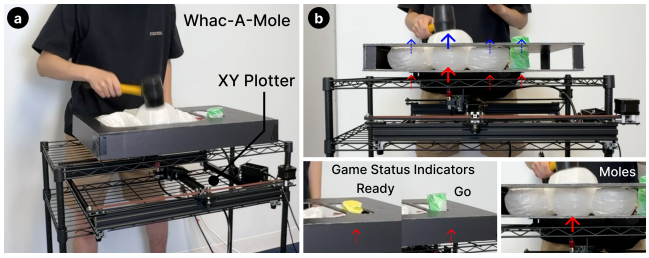


Figure 17: GadJets remake of Whack-A-Mole game with object tracking. a) Overview b) Setup close-up. XY Plotter moves the nozzle and shoots air jets to inflate moles and indicate game status.

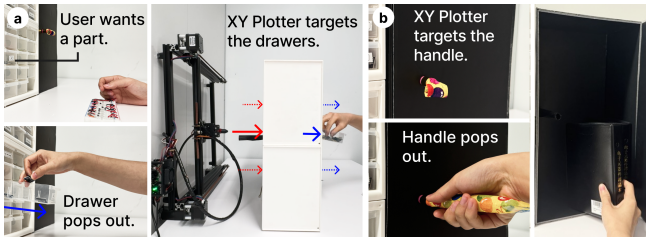


Figure 18: An actuated shelf and a cabinet.

6.3 Fixed and hand-held Nozzles (without controlled nozzle bases)

GadJet has the potential for expansion, without an actuate base for the nozzle, as well. For example, a fixed nozzle could provide actuation to body-worn or handheld modules affecting bodily interaction without any electronics or batteries on the body (Figure 19a). We foresee that such cases may be powerful when combined with considering an environment where the user's body is assumed to be fixed in a specific place (e.g., passive wearable modules combined with a chair-installed nozzle). Figure 19b, furthermore, demonstrates the nozzle being held by the user, allowing them to aim at environmentally installed passive modules to playfully configure the modules using the air jet. This can be extended to a shooting gaming scenario as well.

7 LIMITATIONS & FUTURE WORK

This paper introduces a general approach of GadJet, employing an air jet as a way to tetherlessly actuate passive mechanisms and objects, exploring a preliminary design space and prototypes to

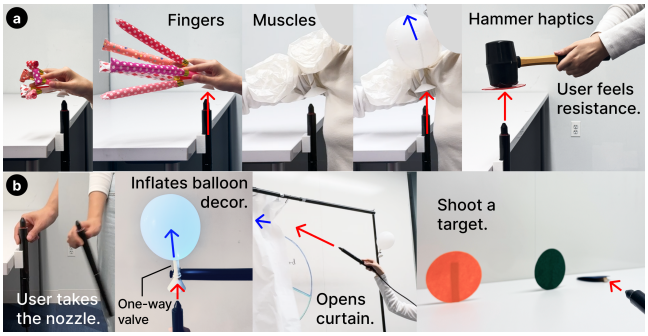


Figure 19: On-body GadJets and handheld nozzle. a) Table-mounted nozzle and GadJets-on-body. b) Handheld nozzle and GadJet modules in the environment.

open up this new approach for actuated, shape-changing UIs. While the approach provides unique air-based, contactless actuation, there are challenges that have to be addressed in future research.

One primary limitation of the proposed approach is the **noise**. For example, the air compressor we employed in our prototype generates approximately 60 dB of noise, which can be unsuitable for quiet environments. The noise could be mitigated by using sound-absorbing enclosures or insulation materials, while future nozzle design could be explored to reduce the noise.

Secondly, air jets may **move unintended objects in the environment**, disturbing the users. Although our demonstration introduced ways to adhere the GadJet modules to secure them in the environment, the air can disperse widely, potentially bowing away unintended objects or disturbing users themselves. As our GUI software has preliminarily explored ways to visualize the air range and the tracked modules, future research could extend this to actuate target objects without disturbing surrounding objects by simulating and controlling the angle and pressure. Employing a robotic arm-based 3 DoF nozzle may be a promising potential solution to reposition the nozzle in the 3D space (Figure 20).

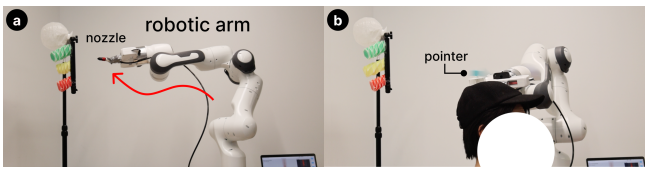


Figure 20: Concept for future 3 DoF air-jet actuation system using robotic arm.

Thirdly, **the nozzle selection and optimization** is another future challenge to be addressed, as this paper focused on empirically characterizing a limited number of commercially available nozzles. While our characterization revealed generic guidance on the selection of the basic geometry of nozzles, future work could incorporate aerodynamics simulation for nozzle design using numerical methods such as the finite volume method (FVM). This would allow the visualization of the air range based on the nozzle geometry (potentially together with environmental geometry), reducing reliance on manual data collection. Additionally, enabling users to fabricate their own air-tight nozzles, such as flat and wide nozzles for broad coverage or multi-head nozzles for specialized applications, could further enhance the versatility of the air jet actuation systems.

Fourthly, we acknowledge that our system exhibits **inefficient energy usage** due to air pressure loss through dispersion, necessitating significantly higher air pressure for certain actuations, unlike tethered, tubing-based inflatables. Partially because of this, we had to employ a large air compressor to fully explore this approach. Future systems could mitigate this by nozzle design for energy efficiency and a compact, powerful compressor.

Lastly, the general precision and robustness of the modules, as well as the air-jet control approach, need to be further addressed in future work. Balancing cost, safety, robustness, noise, and precision—and investigating their trade-offs—will be crucial for identifying feasible and practical application spaces. Nevertheless, we hope this paper inspires future HCI researchers to explore this new contactless energy conveyance method toward making our environments and objects more interactive and dynamic.

8 CONCLUSION

This paper presents GadJets, a novel approach for remotely and contactlessly actuating passive mechanisms and materials using concentrated air jets. We designed and implemented multiple types of GadJets modules, each converting air jets into distinct actuation modes such as inflation, deflation, and rotation. These modules demonstrate how directional airflow can be transformed into behaviors without physical contact. To generalize these interactions, we outlined a design space that identifies key architectural patterns and design primitives specific to air-jet-based TUIs. In addition, we proposed a workflow for empirically capturing air range data and integrated it into a GUI tool, allowng users and the system to selectively actuate the modules during interactive applications. Our work envisions a future in which directed air jets are seamlessly embedded into physical environments, selectively actuating modular passive elements.

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