

# Fizzy: The underactuated robotic ball for interactive and engaging rehabilitation

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*Abstract: Maintaining long-term engagement in physical therapy for pediatric and elderly people remains a clinical challenge. This work formally introduces Fizzy, a novel, low-cost, active, spherical robotic platform designed for rehabilitation and preventive healthcare in indoor unsupervised environments, integrating play with targeted exercise. Fizzy utilizes a single-motor, underactuated mechanism, to provide a simpler and more durable alternative to complex multi-actuator robotic ball designs. While this approach maximizes safety and accessibility, it introduces engineering challenges. This work shows the mechanical architecture and outlines the key technical foundations required for therapeutic integration.*

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## I. Introduction

Engaging in consistent and tailored physical activity is critical for promoting motor function for individuals with neurological and neuromuscular disorders. However, maintaining motivation and continuity outside of clinical settings remains a challenge. Standard, repetitive exercises often lack the inherent playfulness required for long-term commitment, leading to suboptimal therapeutic outcomes.

To address this issue, researchers have explored the use of social robots to provide dynamic, personalized interaction [1]. While traditional social robots often employ anthropomorphic forms, these designs introduce technical complexity, increased cost, and ethical risks associated with pseudo-sociality [2]. To overcome these limitations, the concept of Fizzy, first introduced by Boon [3], realizes the potential of social robots through a simple, abstract robotic ball that integrates therapeutic goals and principles of play [4]. Preliminary work has shown that participants engage with Fizzy by kicking, retrieving, and with dynamic games as they would with a regular ball [5], encouraging motor movements, as shown in Figure 1.

Although several designs for robotic balls have been proposed [6], these designs often rely on complex multi-actuator configurations, leading to high costs and maintenance difficulties. Fizzy addresses these gaps by employing a novel, single-motor, underactuated mechanism. This technical architecture is detailed in this



Figure 1: A child interacts with Fizzy, which uses interactive play principles to encourage physical activity © IRT

paper, enabling a mechanically simpler, lower-cost, and energy-efficient system compared to complex multi-actuator spherical robots.

## II. Application requirements and design

Fizzy is designed to meet the demands of rehabilitation and preventive healthcare for pediatric and elderly populations. The core objectives, represented in achieving low cost, ensuring safe use in indoor unsupervised environments, and maintaining high interactive maneuverability, dictated the following design requirements.

### 1. Safety and durability

The robot must withstand high-impact interactions, including kicking and throwing, while ensuring the users' safety and avoiding mechanical failure of the system.

2. *Accessibility and simplicity*  
To facilitate widespread adoption, the system must remain inexpensive, reproducible using basic manufacturing techniques, and easy to operate and maintain, requiring no external sensing infrastructure in the environment.
3. *Privacy-centric operation*  
The system ensures user privacy by operating without collecting visual or audio data. All necessary computations, including activity analysis, are performed onboard, eliminating the need for external data transfer and analysis.

Fizzy's mechanical design is centered on employing a single-motor, underactuated mechanism. The system consists of an outer shell and a single internal rotating block containing the motor, battery, and electronics. For *safety and durability*, the robotic ball employs a flexible outer shell and internal shock-absorbing components [7], which ensure impact tolerance and prevent contact with the rotating block.

For *accessibility and simplicity*, Fizzy achieves locomotion by utilizing a changing mass distribution mechanism that results in a non-diagonal inertia tensor. The internal rotating block is mounted on an axle that is offset by a distance  $d$  from the geometric center of the ball. The center of mass of this rotating block is also purposefully offset by a distance  $r$  from the eccentric axle. This configuration creates an intentional mass imbalance. Rotating the block changes mass distribution, which generates a torque that initiates and sustains the ball's rolling [8]. By choosing  $r = d$ , the overall ball can have a mass distribution like a sphere for a particular motor angle, allowing it to behave like a normal ball. For all other motor angles, the change in mass distribution causes the ball's self-initiated rotation.

For *privacy-centric operation*, all state estimation and control relies on internal inertial sensors, a magnetometer, and a controller mounted on this rotating block.

### III. Results and discussion

Simulations and functional prototypes of Fizzy have been developed, validating that the proposed underactuated actuation mechanism enables reliable rolling, turning, and playful motions [4, 9]. While the mobility mechanism is implemented, some key technical components remain active areas of research.

1. *Sensing and state estimation*  
Since the IMU and magnetometer are mounted on the rotating internal block, the raw measurements do not directly reflect the external shell's pose in the global frame. Future work will use sensor fusion, integrating sensor data, Simultaneous Localization and Mapping (SLAM), and kinematic modeling, to estimate Fizzy's pose and interactions within the environment.
2. *Control*  
Fizzy's single-motor design provides 2D mobility using an underactuated system. Reinforcement learning has shown success in controlling Fizzy's trajectory in simulation [9], and future work is

needed to investigate robust control policies for Fizzy in real-life environments.

3. *Clinical reliability and adaptive interactions*  
Deploying Fizzy for rehabilitation requires addressing the medical requirements for safe and efficient human-robot interaction. Future work is needed to focus on developing closed-loop adaptive behaviors, refining the sensing/control pipelines, and conducting controlled studies to assess the therapeutic value of Fizzy.

### IV. Conclusion

Fizzy represents a step toward accessible and engaging rehabilitation robotics. Its novel underactuated design balances safety, durability, accessibility, and privacy-centric operation. The defined engineering challenges, including state estimation, control, and clinical reliability, provide the roadmap for future research. By resolving these issues, Fizzy can transition from a prototype to a robust therapeutic device capable of real-time behavior adaptation in response to human-robot and robot-environment interactions. This adaptive behavior is essential for encouraging physical activity and maximizing long-term therapeutic adherence.

#### AUTHOR'S STATEMENT

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