luhbots
Extended Team Description for RoboCup 2026

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Abstract This paper presents the design and experimental evaluation of a dribbling device and damping assembly for RoboCup Small Size League robots with integrated damping and spin-control capabilities. Systematic drop tests on five silicone compounds identify SH10 as the most suitable roller material, exhibiting a significantly reduced coefficient of restitution compared with SH45. At system level, ball reception tests across a range of incoming speeds, show that the new damping assembly and SH10 rollers substantially reduce rebound distance and improve ball retention relative to the previous design. Dual independently driven rollers further enable controlled spin manipulation and reproducible curved shots through differential roller rotational speeds. These results demonstrate that the proposed dribbling device combined with the damping assembly overcomes key limitations of the prior mechanism and enhances ball-handling performance in high-speed, game-relevant scenarios.

1   Introduction

Precise ball control and reliable ball reception are decisive factors in Robot Soccer Small Size League (SSL) matches. The ability to receive passes, absorb opponent shots, and maneuver the ball into favorable positions can determine the outcome of a game. Drawing on our experience from previous competitions, the luhbots soccer team identified the dribbling device as a key component for improving these aspects of play. In the 2024 ETDP, our offensive game strategy was described in detail [1]. Building on that foundation, the focus of the current work is the mechanical design of the new generation of robots. Due to ongoing development, the team did not participate in the 2025 RoboCup in Brazil and the additional development time allowed us to refine and experimentally evaluate a redesigned dribbling device.

The new dribbling device is designed to enhance ball handling while remaining fully compliant with the RoboCup SSL rules. This paper first reviews the previous dribbling device design and identifies its limitations. Based on these

insights, we present the new design and its underlying principles, followed by experimental investigations into key performance aspects. In particular, this work investigates the selection of suitable contact materials for effective restitution control, the ball reception performance of the robot, and its ability to generate curved shots. Finally, we discuss the experimental results in the context of competitive play and assess the applicability of the new design for real RoboCup matches.

2   Previous Dribbling Device Design

In an SSL soccer robot, the dribbling device is responsible for maintaining possession of the ball by imparting a backward spin using a powered dribbling device roller. The previous dribbling device design, shown in Fig. 1, was described in earlier TDPs [2,3] and follows the standard configuration commonly used in the league[4,5].
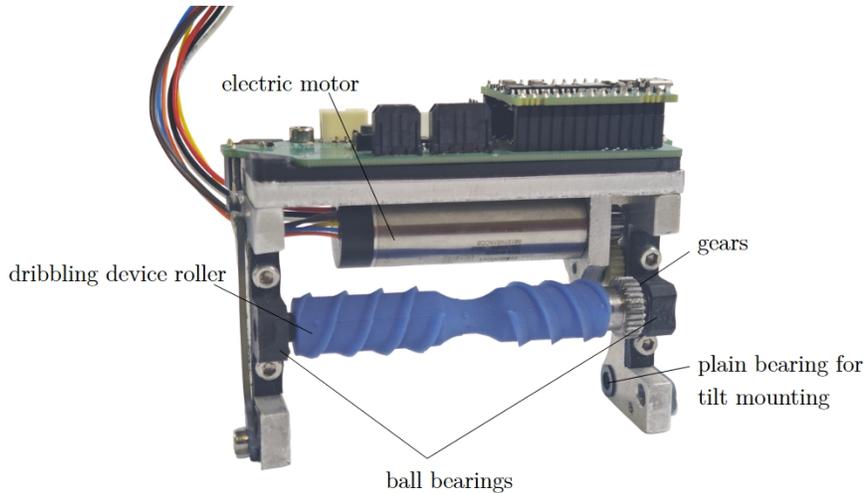
**Figure 1.** The previously used dribbling device

An electric motor transmits torque to a metal shaft via a single-stage spur gear train comprising three gears made of polyacetal and steel. The shaft is supported by two ball bearings mounted near its ends, and a silicone layer is cast around the central section to form the powered dribbling device roller in contact with the ball. The dribbling device mounts on one bolt and plain bearing per side, allowing backward tilt into a 3D-printed damper made of colorFabb Varioshore TPU. Printed at maximum temperature to optimize foaming and

minimize hardness, the damper features two bows of differing radii for staged damping hardness.

This design performed adequately in previous tournaments but exhibited several critical issues. Excessive gear wear occurred due to poor bearing alignment and the soft material used, which eventually led to tooth failures under higher torque loads. Damping performance was also insufficient, causing the robot to lose control of the ball even at lower passing speeds. This issue was further aggravated by the ball rebounding off hard surfaces such as the not dampened frame sides. Together, these shortcomings led to a significant reduction in ball control and handling reliability, necessitating further improvements to the design.

3 New Dribbling Device Design

The new dribbling device design (Fig. 2) was developed to address the limitations of the previous version, with the primary goal of achieving reliable and consistent ball control. The design focuses on improving damping characteristics to absorb passes at speeds up to $4\,\mathrm{m/s}$ without rebound, enhance dribbling precision, and maintain control when driving backwards at speeds up to $3\,\mathrm{m/s}$.
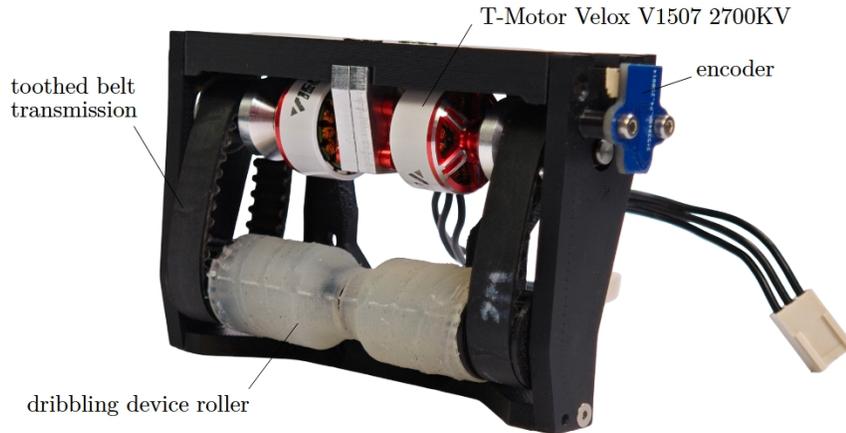
Figure 2. The new dribbling device with independent units

To meet these requirements, the new design introduces several major differences from conventional dribbling devices. Most notably, the main dribbling device roller is divided into two independently driven units, improving ball handling during high-speed interactions. Each unit consists of a hollow shaft covered with a silicone mantle for optimal friction and is mounted on a steel axle. The

units are powered by two independent drone motors (T-Motor Velox V1507 2700KV) via a toothed belt transmission with a gear ratio of 1.33. This setup leverages the high power-to-size ratio of drone motors while maintaining a lightweight drivetrain that minimizes rigid contact surfaces and reduces unwanted rebound. The result is a pair of independently controlled dribbling device rollers, each with its own drivetrain, motor, encoder, and electronic speed controller (ESC). Each ESC uses a custom control driver that alleviates inefficiencies typical of drone motors operating under high torque and low rotational speeds.

The primary motivation for dividing the dribbling mechanism into two independent units is to achieve more precise control over the ball's rotational dynamics. A similar concept is already used in the Robocup Middle Size League, which heavily inspired us to implement a two-roller design in SSL. By actuating each unit individually, the robot can actively regulate both the magnitude and direction of the ball's spin. This additional degree of freedom enables advanced ball–robot interactions, including controlled curve shots and more adaptive dribbling behavior under varying dynamic conditions. The effectiveness of this approach is evaluated in Section 7. An additional challenge in the design process of the improved dribbling device is the selection of suitable materials for impact damping while maintaining reliable contact with the ball. This selection process is informed by experimental investigations described in Section 5. The effectiveness of the resulting material and mechanical design is subsequently evaluated for the complete system in Section 6.

4   Modeling of System Dynamics During Ball Impact

To accurately describe the system's behavior during ball impacts, its response can be represented using classical mechanical elements. A damper dissipates kinetic energy as heat, while a spring stores a portion of the mechanical energy and returns the dribbling device to its initial position after impact. For linear motion, the dribbling device can be modeled as a single-degree-of-freedom mass–spring–damper system:

$$m\,\ddot{x}(t) + c\,\dot{x}(t) + k\,x(t) = F_{\text{ext}}(t),$$

where $F_{\text{ext}}(t)$ is the external force exerted on the dribbling device by the ball during impact. The terms $m\,\ddot{x}(t)$, $c\,\dot{x}(t)$, and $k\,x(t)$ denote the inertial force due to the linear acceleration of the dribbling device mass, the speed-dependent damping force, and the displacement-dependent spring force, respectively. Proper selection of the dribbling device mass m, damping coefficient c, and spring stiffness k is essential for a reliable response. The generation of $F_{\text{ext}}(t)$ can be approximated using a one-dimensional central impact model. This model is exact if the dribbling device roller contacts the ball at its center height. In practice, the dribbling device roller is slightly offset, but the horizontal linear guide constrains its motion predominantly along the ball's direction, making the one-dimensional approximation reasonable. The change in ball speed Δv_{ball} during impact produces

an impulse given by:

$$\int F_{\text{ext}}(t)\, \mathrm{d}t = m_{\text{ball}}\, \Delta v_{\text{ball}}.$$

The total impulse consists of a compression phase followed by a restitution phase. The restitution phase governs the separation after maximum compression and thus the ball rebound. Its magnitude depends strongly on the coefficient of restitution e: as $e \to 0$, the restitution phase diminishes and the impact approaches a perfectly plastic collision. In reality, the total impulse and the dynamic response of the system occur simultaneously and mutually influence one another. The damping assembly (see section 6) begins to move immediately upon start of the impulse, and forces are continuously transmitted between the ball and the damping assembly throughout the entire contact duration. This interaction makes a complete analytical description of the system challenging. Despite this complexity, analyzing the total impulse and the dynamic response of the dribbling device separately provides valuable insight. Such a decomposed approach allows for practically applicable design conclusions for the configuration of the dribbling device roller and the associated mass–spring–damper system.

5   Silicone Rebound Tests

Shock-absorbing materials are essential to control rebound behavior, as established in the preceding dynamics model. In particular, minimizing the coefficient of restitution e reduces the energy returned to the ball during impact and thus directly influences the rebound, as described in Section 4. Consequently, the contact material must be carefully selected to achieve the desired energy absorption. Silicone-based materials were selected for evaluation due to their inherently low coefficients of restitution and high compliance [6]. Although e is generally expected to decrease with decreasing Shore hardness (ISO 48-4), this trend is not universal and must be verified experimentally. For the evaluation only addition-curing silicones were selected, because they can be reliably cast in 3D-printed molds without inhibiting the cross-linking process. This allows complex geometries of the dribbling device roller to be manufactured easily and consistently. For this study, the following silicone materials bought from Silikonfabrik [7] were selected and are hereafter denoted as "SH" followed by their Shore hardness on the A Scale (e.g., SH10). SH45, which is currently used for coating the dribbling device roller, serves as reference for assessing the shock-absorbing properties of the other candidate silicones.

Table 1. Selected silicones

Name	Shore A
SF00	00
Silixon 10	10
Silixon 25	25
SF33	33
SF45	45

5.1   Experimental Setup and Procedure

Five different candidates shown in table 1 were tested. Standardized cuboid specimens with dimensions 70 x 50 x 13.5 mm were molded for consistency. Each specimen was placed on the floor adjacent to a table, from which a golf ball was released from a fixed height of 0.74 m onto the specimen's center. A camera recorded the impact and subsequent rebounds, while a tape measure positioned next to the table provided a spatial reference. The maximum bounce height for each drop was determined by analyzing the video frames. Ten drops were performed for each specimen to ensure statistical reliability.

5.2   Analysis and Evaluation of Experimental Data

All the measurements for each specimen were used to compute the mean bounce height and standard deviation. Fig. 3 shows the resulting distributions as a boxplot, with the mean marked by an 'x'.
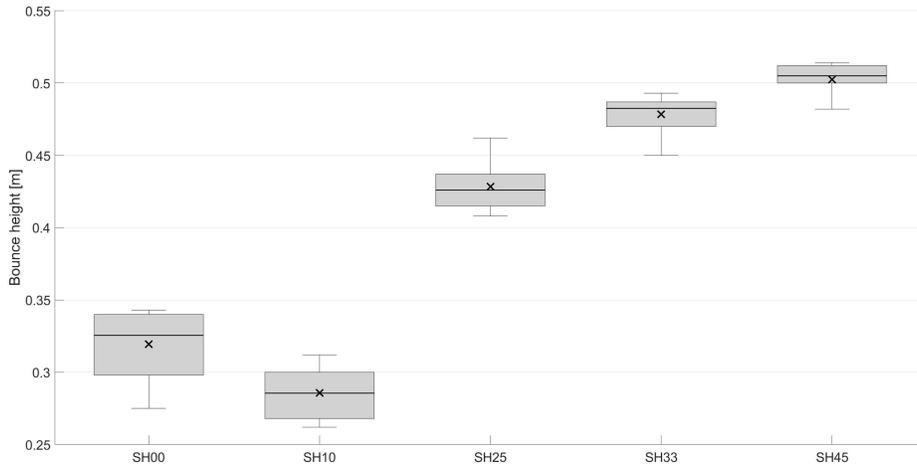
Figure 3. Bounce-height distributions for each specimen

The standard deviations are small relative to the mean bounce heights, indicating good repeatability of the measurements. The largest relative variation

(7.3 %) occurs for the specimens with the lowest bounce heights, whereas specimens with higher rebound exhibit lower variability. The experimental data are therefore considered sufficiently reliable for comparative analysis. As expected, the bounce height generally increases with increasing Shore hardness of the silicone. SH00 deviates slightly from this trend and shows a marginally higher bounce height than SH10. SH10 exhibits the lowest average bounce height of 0.29 m, indicating the most effective damping among the tested materials. The fraction of the ball's kinetic energy absorbed by the silicone is given by

$$\frac{E_{\text{absorbed}}}{E_{\text{kinetic}}} = 1 - \frac{h_{\text{bounce}}}{h_{\text{drop}}},$$

where h_{bounce} is the rebound height and h_{drop} is the initial drop height. For SH10, 61.4 % of the ball's kinetic energy was absorbed.

5.3   Summary

The experimental results largely confirm the assumption that lower Shore hardness leads to a lower coefficient of restitution e. Consequently, materials with lower Shore hardness are more effective at minimizing ball rebound, as they absorb a larger portion of the ball's kinetic energy. Among the tested silicones, SH10 demonstrated the highest energy absorption. In addition to damping performance, mechanical robustness was considered. Specimens with higher Shore hardness showed a lower tendency to crack, whereas softer materials were more prone to mechanical failure. Considering both criteria, SH10 was selected as the dribbling device roller material, offering high energy absorption and adequate structural integrity for reliable operation.

6   System-Level Damping Evaluation

Two damping concepts were evaluated for the system. The first concept relies on an eddy-current brake, in which the motion of a conductive element is damped by magnetically induced currents. However, achieving sufficient damping requires strong permanent magnets and a relatively large installation space, making this approach impractical for integration into the robot. The second concept employs compact hydraulic shock absorbers, which are far more space-efficient and better suited to the available design envelope. Representative characteristics of a fast shot impacting the dribbling device were used and compared with manufacturer data in order to select a suitable hydraulic shock absorber with an appropriate damping coefficient c and spring stiffness k. As shown in section 4, the dribbling device mass is also an important parameter. However, it was strongly constrained by design requirements and was therefore not treated as a free design parameter.

Additionally, a dedicated damping design was implemented that damps not only the dribbling device but also the chipper plate during ball reception. Since the chipper plate, like the dribbling device, is in direct contact with the ball,

insufficient damping in this element would likewise promote ball rebound. The damping assembly is shown in Fig. 4.
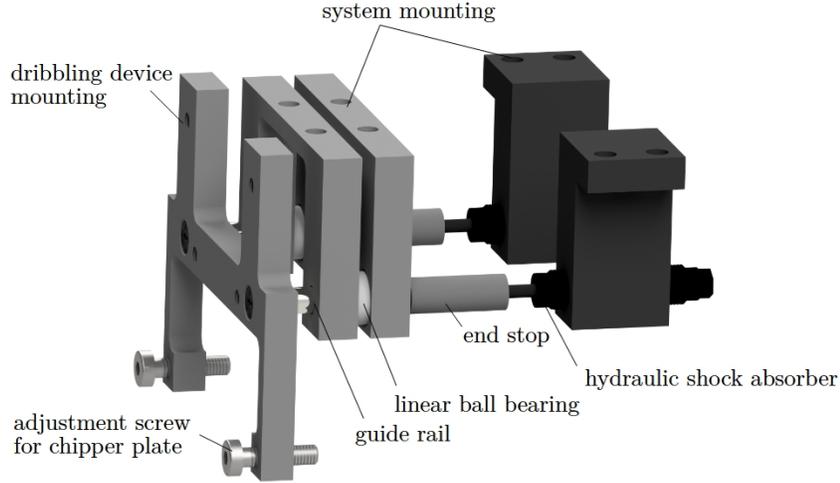

Figure 4. Damping assembly

In real match scenarios, the robot must be able to receive balls over a wide range of speeds. Therefore, it is essential to characterize the ball reception performance for varying ball speeds. In this section, the ball reception performance of the new system, comprising the dribbling device and damping assembly, is experimentally evaluated at different ball speeds. The results are compared with those of the previous system and with the new system using the former silicone material, in order to assess both the overall performance gain and whether the SH10–SH45 difference observed in isolation persists at the full-system level.

6.1   Experimental Setup and Procedure

To evaluate the damping properties of the overall system under realistic conditions, a ball was shot by a second robot from a distance of 1.15 m towards the dribbling device. The rebound distance after impact was measured using a tape measure, and it was also recorded whether the ball was subsequently retained by the dribbling device. Three impact speed settings of 2 m/s, 3 m/s, and 4 m/s were calibrated once at the impact position. For each shot, the initial shot speed was measured with a dual light barrier positioned approximately one ball length in front of the shooting robot. Each experimental condition was repeated 20 times to improve statistical reliability and support robust data analysis.

6.2   Analysis and Evaluation of Experimental Data

The measurement data shown in Fig. 5 were acquired as described in the previous section.
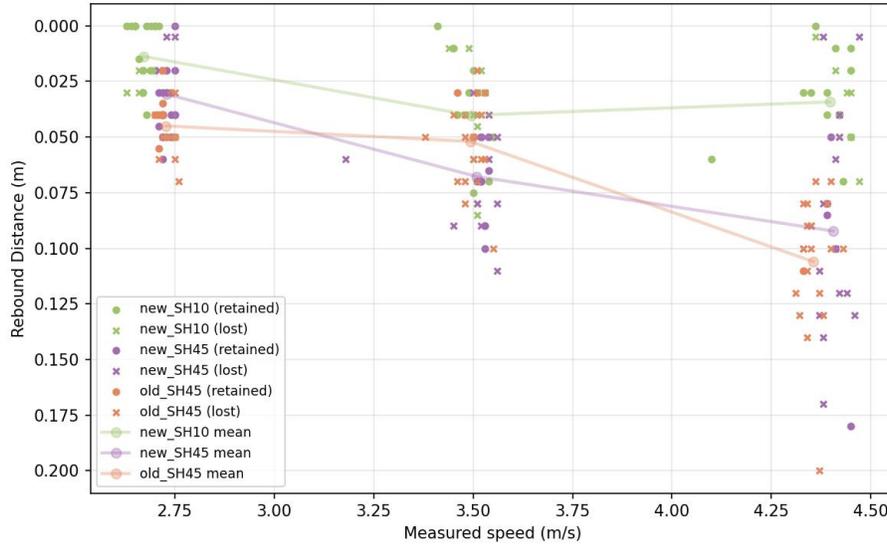
Figure 5. Rebound distance and ball retention

The X-axis of this diagram represents the recorded initial shot speed, whereas the rebound distance is plotted along the Y-axis. During tests with the new SH10 design, the system successfully retained an average of 13 out of 20 shots. In comparison, the new system equipped with SH45 retained an average of only six shots, while the previous robot design was able to retain merely four shots. The rebound distance increases noticeably with rising impact speeds for both the previous design and the new design with SH45. However, at an impact speed of $3\,\mathrm{m/s}$ the previous design exhibits a lower average rebound distance compared to the new design with SH45. For the new design with SH10, the rebound distance remains lowest across all tested speeds.

6.3   Summary

The results demonstrate that the new damping assembly markedly improves overall damping and ball reception compared with the previous design, as both the SH45 and SH10 variants exhibit reduced average rebound distances across most impact speeds. The overall improvement is most pronounced for the system with the soft-silicone roller SH10, which consistently yields the smallest average

rebound distances and thus the most reliable ball retention, especially at high shot speeds.

7   Curved Shot Generation

When the spin of the ball causes slip relative to the ground, a friction force with a defined direction acts on it. In conventional dribbling device designs, this friction force points from the ball toward the dribbling device, so that the ball is pulled toward the robot during dribbling and, in the case of spinning shots, partially returns toward the robot after being shot. If the spin direction is changed relative to the shot direction, the direction of the friction force also changes, so that the resulting acceleration no longer acts opposite to the initial shot direction but instead points in a new direction. Consequently, the ball follows a curved rather than a straight path.

Two concepts for generating such curved shots have been implemented previously. The team OP-AmP presented curved shots using a rotatable kicker, which decouples the shot direction from the unchanged spin direction of the ball [9]. However, a rotatable kicker requires substantial installation space and therefore cannot be integrated into the new robot. A second approach was used by the team Mannheim Tigers: when the robot is dribbling the ball and then abruptly rotates by a small angle, the inertia of the ball causes a temporary misalignment between its spin direction and the robot. If the ball is shot before this transient alignment process is completed, a curved shot is achieved. As described in Section 3, the independent control of the two dribbling device rollers enables precise manipulation of the ball's spin direction. The experiment described in this section evaluates the feasibility of using this control strategy to generate curved shots. The objective is to execute a shot that, due to an imposed lateral spin, follows a curved path during travel. For this purpose, different shot speeds and rotational speed ratios of the two dribbling device rollers are tested, and the resulting paths are analyzed and evaluated.

7.1   Experimental Setup and Procedure

The new robot was placed stationary in the lower-left corner of a small test field and oriented toward the upper-right corner. The rotational speeds of the two dribbling device rollers and the ball's shot speed were systematically varied. The dribbling device rollers rotational speeds were calibrated individually under no-load conditions using an external tachometer, and the initial shot speed was measured with a dual light barrier positioned 0.30 m in front of the dribbling device. Ball motion was recorded by an overhead camera, and the ball coordinates were obtained via the SSL Vision system. In total, nine measurement series with different parameter settings were conducted, with 10 to 20 shots recorded for each parameter set.

7.2   Analysis and Evaluation of Experimental Data

The experiment demonstrates that spin aligns with the direction of the higher roller rotational speed, with spin angle increasing with the speed differential between the two rollers. In Fig. 6, 2D vision-system coordinates are plotted, ordered by shot speed, left roller speed (in shot direction) and right roller speed.
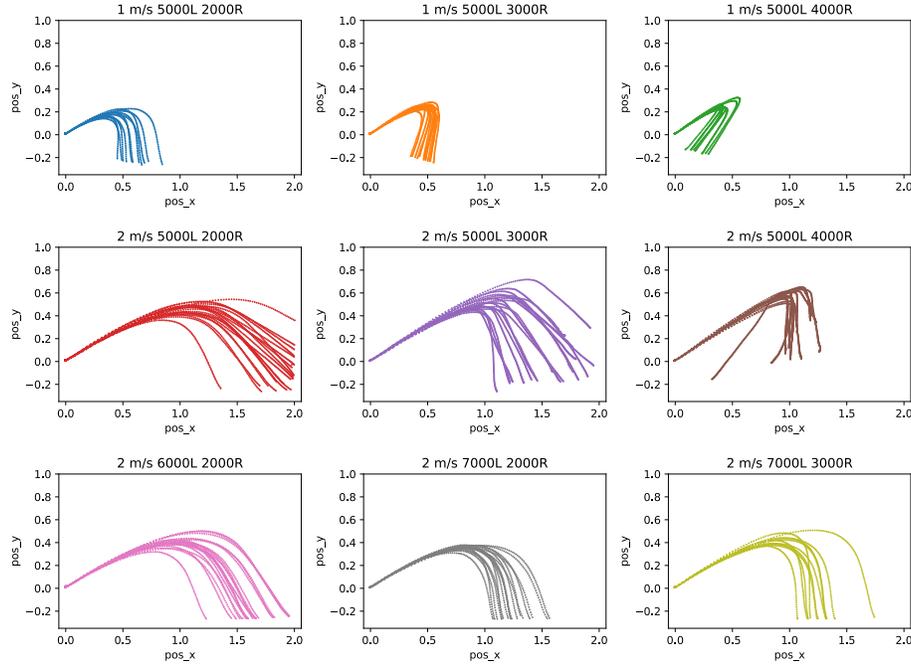
Figure 6. Curved Shot Paths by Configuration

The curved shot paths comprise three sections: initial linear, curved, and final linear (Fig. 6). In the first, spin has negligible effect due to insufficient traction. The curved section emerges as traction induces spin-directed force, overcoming shot inertia. The final section is spin-dominated, yielding near-linear motion in the spin direction. This is pronounced at low speeds (Fig. 6 first row). Higher speeds (Fig. 6 middle/bottom rows) bias the final path toward shot direction. The initial linear section lengthens with increasing shot speed. Path dispersion peaks in the curved section due to variations in ball speed allowing greater travel distance and imprecise roller speed control from motor limitations. Final paths converge parallel, with higher roller speeds producing faster ball motion governed by the maximum of the two rotational speeds. Outliers arise from comparatively high shot speeds or strongly deviant spin, deviating markedly from clustered paths.

7.3   Summary

The experiment demonstrates that the new two-roller dribbling device enables consistent curved shots with the current setup. The ball path primarily depends on speed, spin direction, and rotational speed, enabling curvature adjustment.

8   Discussion

The presented dribbling device meets RoboCup SSL requirements. Tests confirm that the new damping assembly and two-roller design exceed minimum standards, enabling safe ball reception across a wide speed range and reliable curved shots. By confidently receiving shots, tactical maneuvers can now be performed as planned. The capability of curved shots expands the tactical action set of the robot, allowing passes and shots that bend around opponents or exploit narrow passing lanes. In competitive scenarios, such curved shots can provide a decisive strategic advantage over the opponent.

Nonetheless, the current evaluation is limited to controlled laboratory conditions and a small test field. The influence of varying carpet properties, ball wear, and opponent contact has not yet been quantified. A thorough evaluation under realistic match conditions is required to confirm that the improved damping, ball reception, and spin control persist reliably throughout tournament play. During curved shots, heat generated by high motor speeds must also be considered. The integrated cooling system requires validation in real competition to prevent overheating or damage to the dribbling device roller material during extended operation. Additionally, system durability requires evaluation. The dribbling device roller material in particular is susceptible to wear due to its low Shore hardness. Furthermore it exhibits centrifugal expansion at high rotational speeds required for curved shots, potentially damaging adjacent components and itself. Practical validation under tournament conditions must confirm that damping benefits outweigh wear effects.

9   Conclusions

The new dribbling device eliminates the main weaknesses of the previous design and meets the performance requirements for RoboCup SSL gameplay, clearly outperforming the previous dribbling device in terms of ball reception and rebound behavior. Compared to the previous system, the integrated damping assembly and the optimized soft-silicone roller material (SH10) significantly reduce average rebound distances at high incoming ball speeds and increase the proportion of passes that are controlled without loss of possession.

Systematic silicone rebound tests and system-level damping evaluations show that SH10 combines high energy absorption with adequate mechanical robustness. These advantages translate from isolated tests to the full system, where SH10 outperforms SH45 both as a standalone roller material and within the

dribbling device, while the new overall design also clearly improves upon the previous system in terms of rebound distance and reception reliability.

The division of the dribbling device into two independently driven units introduces a new concept for manipulating the ball's spin, enabling more advanced ball-handling behaviors such as actively shaping the ball path and decoupling spin control from purely translational dribbling motions. Under test conditions on the small test field, curved paths can be generated reproducibly by suitable combinations of shot speed and differential roller rotational speeds, although a noticeable spread in the resulting paths remains due to ball–surface interactions and other unmodeled effects. Overall, the new dribbling device design not only remedies the critical shortcomings of the previous mechanism, such as insufficient damping, uncontrolled rebounds at hard contact surfaces and limited spin control, but also extends the functional capabilities of the robot by enabling reliable curved shots and more robust ball reception across a range of operating conditions.

10   Future Work

In the ongoing development of the dribbling device, the primary objectives are rapid self-centering, improved ball control, and enhanced adhesion of silicone to the hollow shaft. To achieve this, silicone will be embedded into cavities and lattice structures within the 3D-printed hollow shaft, creating a form-fit interaction in addition to surface adhesion. This structural integration is expected to increase the mechanical stability of the interface, distribute loads more evenly, and reduce slippage under dynamic operation. Research in this area remains scarce [8], which underscores the novelty and potential impact of this approach. We expect this concept to provide significant performance benefits, particularly at higher rotational speeds where increased spin differentials can be achieved. As shown in section 7, greater spin differential directly correlates with more pronounced shot curvature, offering a measurable advantage in precision play and control dynamics. Future work will focus on quantifying the performance improvements introduced by the form-fit design, including experimental validation of ball control accuracy, centering time, and long-term durability. The upcoming tournament will serve as an opportunity to evaluate whether the newly developed rollers meet the required durability and stability standards over continuous use under competition conditions.

11   Acknowledgments

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References

1. Westermann M. , Pahl T.,de Vries T.,Knackstedt S., Seegemann L.: luhbots soccer team description for robocup 2024, 2024
2. Seegemann L., Zeug, F., Ebbighausen P., Waldhoff L., de Vries T., Sukkar M., Känner M., Weber J.O.: luhbots soccer team description for robocup 2022,2022
3. Seegemann L., Zeug F., Ebbighausen P., Waldhoff L., Westermann M., Knackstedt S., Känner M., Füchsel T., Hart R., Pahl T.: luhbots soccer team description for robocup 2023, 2023
4. Miyajima D., Naito K., Mitsuda H.,Harada K., Nonoyama M., Shirai R., Sato F., Tanaka R.,Dori Y., Sugiura T.: KIKS Extended Team Description for RoboCup 2023, 2023
5. Ommer N., Ryll A., Ratzel M., Geiger M.: TIGERs Mannheim Extended Team Description for RoboCup 2024, 2024
6. Coote C.T.: Measurement of the damping properties of silicone-based elastomers over wide temperature ranges. In: Journal of Sound and Vibration 21, 1972
7. Onlinestore: Silikonfabrik.de, https://www.silikonfabrik.de, accessed 2026/01/12
8. Proper B., Van de Burgt Y., Kuling I. :How to Mould, Bond, and Seal Soft Silicone: Practical Solutions to Common Problems
9. Yoshimoto T., Horii T., Mizutani S., Iwauchi Y., Zenji S.: OP-AmP 2019 Extended Team Discription Paper, 2019