

A Comparative Survey along with design and fabrication of bioinspired Water Strider Robot

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Abstract. Robotics has evolved a lot since its origin. The design of these robots is done based on various aspects, and one such aspect is bioinspired robots, which lies one of the most challenging fields where a robot is developed by mimicking or inspiring from some living creature. Among these bioinspired robots, water strider robots are yet more challenging design which still remains as an area of research for many researchers considering its complex design parameter constraints. In this article an intensive survey is done by considering the research publications and patents that mimic the water strider insect, focusing on surface tension for support and movement. Examining these 53 technical papers and patents, the comparison is made by considering robot designs based on their size, speed, power sources, and materials. Success relies on two key areas: using super-waterproof (super hydrophobic) materials to utilize the water's "skin" and employing flexible, often artificial, muscles for propulsion. Designs range from micro-robots to large floating platforms. Current research focuses on achieving high speed, ability to move quickly, easily, and new applications like oil cleanup. The main challenge remains building robots as efficient and durable as the natural insect. In this article, initially, an exhaustive survey is made on the existing water strider design and also an innovative design for the water strider having the slowest speed compared with other existing water striders is proposed and its performance is analyzed with respect to the positioning of vibrator motor.

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1 Introduction

Nature offers incredible solutions to complex engineering problems. One of the most fascinating examples is the water strider insect (Gerridae), which effortlessly "walks" or glides across the surface of the water. They do this without sinking by exploiting surface tension - the skin-like layer on the water created by molecular cohesion. The fundamental concept of molecular cohesion that creates this "water skin" is visualized in Figure 1.

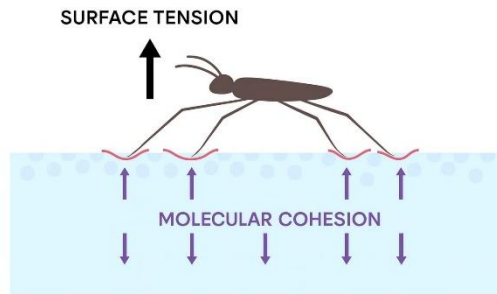


Fig. 1. The Water's Skin – Cohesive Forces at the Surface.

Engineers want to copy the strider's design (bio-inspiration) to create tiny, energy-efficient robots that can perform specialized tasks on water. These robots could be employed for pollution clean-up, water quality checks, and reconnaissance. Beyond Earth, the dynamic control of the strider has even served as an inspiration for the idea of a free-flying space robot [20]. With an emphasis on the particular designs, materials, and mechanisms employed by these bio-inspired robots, this review seeks to clearly compare the solutions discovered throughout the previous 20 years of research. Geometry and material physics are essential to floating. The water's surface bends and forms a dimple when a robot or strider places its lightweight, non-wetting legs on it. The weight is supported by surface tension, which pulls back upward [2]. Figure 2 provides a straightforward illustration of how these forces are balanced between gravity and surface tension.

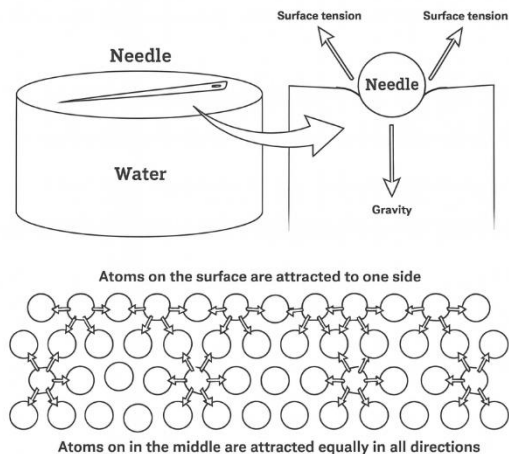


Fig. 2. Hydrodynamic Support: Surface Tension Example with Needle.

The long, thin legs are essential because they optimize the length of the "contact line" with the water, maximizing the sustaining force, as demonstrated by early foundational work by Suter [1] on the fisher spider and Hu, Chan, & Bush [2] on the water strider. Leg configuration is crucial for carrying weight, according to specific design research [11]. The natural water strider sets a high endurance criterion for robotic designers by remaining steady even when struck by powerful external forces, like heavy rainfall [4]. The strider uses a propelling mechanism to push water backward in order to move. The bug is propelled forward by the tiny waves (vortices) created by this push, which transfer momentum without ever shattering the water's surface [3], [28], and [29]. The actuator selected determines the speed and efficiency.

2 Literature Survey

Super hydrophobic legs as shown in Figure 3, which is excellent water repellent are used to prevent the strider from sinking as mentioned in [34], [35]. Aluminium [15] and Graphene-like miniature robots [17] are two sample superhydrophobic materials that emphasize on light weight and durability. Anti-dirt and anti-fouling are two major environmental constraints while considering the coating materials [33].

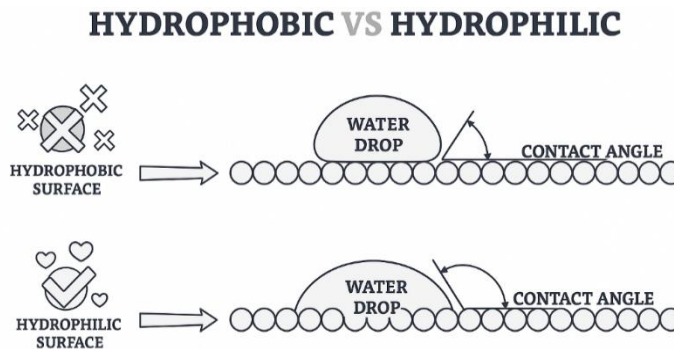


Fig. 3. Hydrophobic vs. Hydrophilic Contact Angle.

Most of the patent related to water strider design ends up with six-legged design that enables the higher stability and consistent footing in any irregular environments. This phenomenon is employed in wide range of design starting from tiny bots to larger one, such as an innovative floating composite material ocean platform, explaining the higher payload capacity. The Table 1 -5 compares the various design constraints and features of the existing the water strider proposed by various research articles.

Table 1. Comparison of existing Bio-Inspired Water-Walker Comparison
(Research Papers)





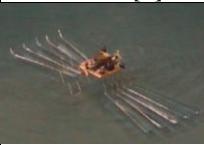

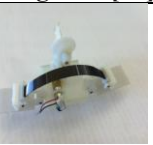

Ref no:	Hu et al [2]	Suhr et al [5]/Song et al [6]	Szuki et al [7]	Zhang et al [8]
Fig				
Weight/size	Natural Insect (10-20 mg)	≈10 mg / 10-20 mm span	5.4g	Micro-robot (μm-mm scale)
Working mechanism	Propulsive Mechanism (Biological Benchmark)	Kinematic Walking (Tripod Gait)	Hexapod Design Principles	Kinematic Walking (Micro-robot)
Materials used /stability focus	Natural Hairs (Non-wetting)	General non-wetting surfaces	Microfabricated Functional Surfaces	Hydrophobic Composite
Movement/speed/efficiency	≈1.5 m/s (max)	< 5 cm/s	Info. Not Available (INA)	≈1 cm/s
Power /control	Info. Not Available (INA) (Biological)	Motor/Linkage Control	Info. Not Available (INA) (Review)	External Magnetic Field

Table 2. Comparison of existing Bio-Inspired Water-Walker Comparison
(Research Papers)

Ref no:	Wu et al [9]	Koh et al [12]	Jiang et al [14]	Sun et al [15]
Fig				
Weight/size	≈2-5 g / 10-20 cm span	1.6 - 1.7 g / 20 mm	≈1.5 g / 20 mm	Info. Not Available (INA)
Working mechanism	Kinematic Walking (Telecontrolled)	Impulsive Jumping (Explosive force)	Impulsive Jumping (Miniature)	Kinematic walking stability focused
Materials used/stability focus	General non-wetting surfaces	General non-wetting legs	General non-wetting legs	Superhydrophobic Aluminum

Movement /speed/efficiency	≈10 cm/s	Jump height: ≈150 mm	Jump height: ≈140 mm	≈10 cm/s
Power /control	Wireless Control (Motor/Linkage)	Spring/Latch Mechanism	Spring/Latch Mechanism	Motor/Linkage Control

Table 3: Comparison of existing Bio-Inspired Water-Walker Comparison
(Research Papers)

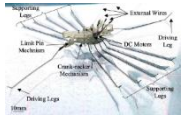
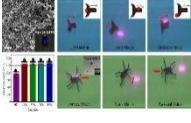
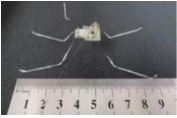
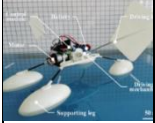
Ref no:	Yan et al [16]	Wang et al [17]	Kin et al [18]	Kim et al [19]
Fig				
Weight/size	≈4.9g/ 160×195×16mm	Millimeter-scale	≈1.1 g / 40 mm	Info. Not Available (INA)
Working mechanism	Kinematic Walking (Flexible Drive)	Kinematic Walking (Agile)	Artificial Muscle Walking (High Force)	Dynamic Sliding (Momentum-Based)
Materials used /stability focus	General non-wetting surfaces	Superhydrophobic Graphene-like	Hydrophobic Materials	Optimized superhydrophobic surface
Movement /speed/efficiency	≈15 cm/s	≈3 body lengths/s	2_body lengths/s	Max speed: 3.8 m/s
Power /control	Flexible Driving Mechanism	Photothermal Actuation	Artificial Muscle Actuator	Motor/Linkage + Optimized Trajectory

Table 4. Comparison of existing Bio-Inspired Water-Walker Comparison
 (Research Papers)

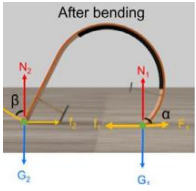
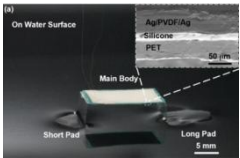

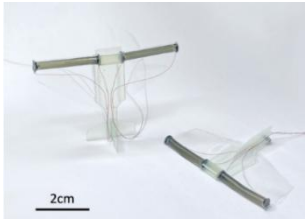
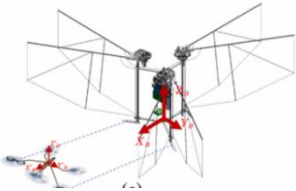
Ref no:	Zhu et al [21]	Zhao et al [22]	Ortega-Jimenez et al [23]
Fig			
Weight/size	Small (Very Low Weight)	Insect-scale (low mg range)	Biological/Robotic Analogy
Working mechanism	Soft/Amphibious Locomotion	Fast-Moving/Steerable Soft	Elastocapillary Fans (Agile Turning)
Materials used / stability focus	Soft/Light-responsive materials	Hydrophobic/Soft Polymer	Bio-inspired Flexible Structures
Movement/speed/efficiency	≈ 0.1 body lengths/s	Max ≈ 30 body lengths/s	Turning rate: $\approx 200^\circ$ /s
Power /control	Light-Driven Soft Actuator	Soft Actuator (Integrated)	Info. Not Available (INA) (Theoretical/Biological)

Table 5. Comparison of existing Bio-Inspired Water-Walker Comparison
 (Research Papers)

Ref no:	Zhang et al [24]	Zheng et al [25]
Fig		
Weight/size	2 cm	Info. Not Available (INA)
Working mechanism	Soft/Multi-modal (Surface & Underwater)	Flapping-Wing (Multi-Modal)
Materials used / stability focus	Dielectric Elastomer	Elastic Passive Legs
Movement/speed/efficiency	Max speed: ≈ 4 body lengths/s	Info. Not Available (INA)
Power /control	Dielectric Elastomer Actuator (DEA)	Motor/Linkage Control

The water strider designs vary from simple and reliable walkers [6], [7] to complex and unpredictable impulsive movement (like jumping [14], [15]) in order to overcome the barrier, which is discussed in detail by [27]. Recent research focus on advanced agility and steering [22], [23] or multi-modal systems (walking and swimming) [25]. An innovative way of using non-mechanical propulsion for uneven surface, such as the Marangoni effect [30][36].

3 Methodology

The methodology as shown in Fig 1 starts with design of water strider in simulation environment namely Coppelasim and followed by the performance measure of this water strider in this simulation environment. The real-time water strider, which weighs 4.6 grams and measures 7 cm in width by 12 cm in length, is then constructed. This water strider is allowed for performance measure on the surface of water stored in Fish tank.

The time taken to reach from starting point to destination point in real time testing is also tabulated, finally the results obtained in simulation and real time fabrication is also compared. The entire process is done on trial and error basis as the key focus is given to monitor that the weight of the proposed water strider should not exceed in way so that the water strider bot is not getting immersed into the water at any cost. Hence adding more motors would always remain as a major constraint for adding the weight of the water strider.

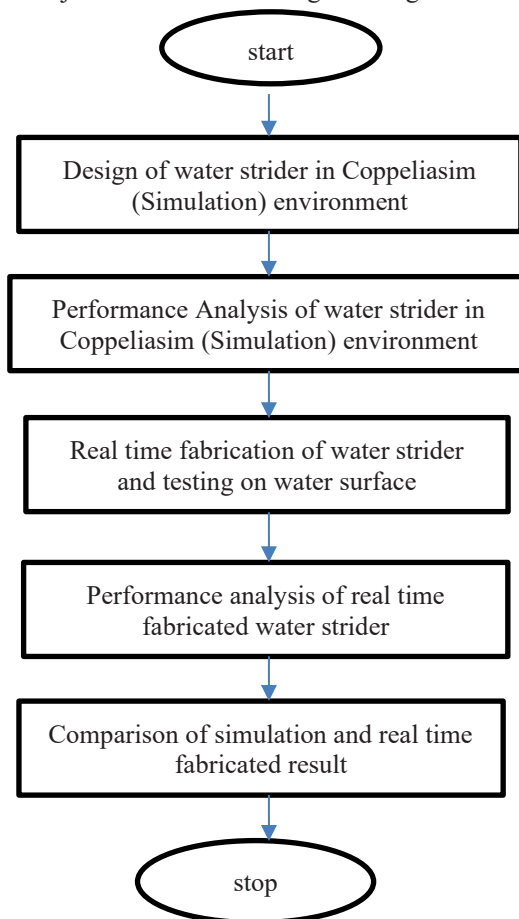


Fig. 4. Flowchart showing the methodology.

4 Simulation

The design of proposed water strider is made in Coppeliassim software and the dynamic stability of this water strider is tested with respect to its movement from start and destination point. In coppeliassim environment, the water surface environment is used to check the locomotion of the proposed water strider on the surface of water. The time taken for this strider movement from starting point to destination point (considered as 30 cm distance) is tabulated and this is compared with the performance analysis of the fabricated hardware on the water surface. The Fig 2 shows the top view of the water strider and Fig 3 shows the side view of the water strider. As shown in table 10, the time taken both in simulation and real time testing is noted for the graphical representation.

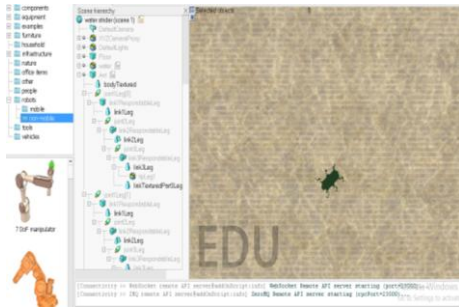


Fig 5. Top view of water strider on water surface in simulation environment (Coppeliassim)

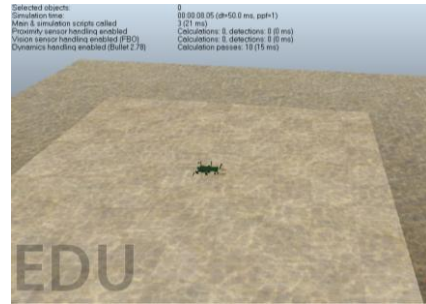


Fig 6. Side view of water strider on water surface while simulation(Coppeliassim) is running

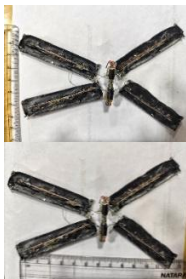


Fig 7. Water strider dimension 7x12 cm



Fig 8. Waterstrider on water surface from start position

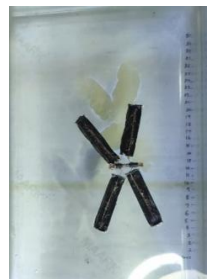


Fig 9. Waterstrider on water surface on mid-way to destination

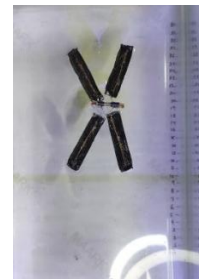


Fig 10. Waterstrider on water surface on reaching destination at 30 cm

Table 10. Simulation Vs Real time Fabricated

Distance(cm)	Simulation (seconds)	Real time Fabricated (seconds)
5	8	12
10	12	20
15	20	28
20	28	36
25	38	45
30	46	56

5 Real time fabrication

The real water strider is fabricated with four legs having ended with pad shaped hydrophobic material that enables the easy float of the water strider over the water surface. The center part of the water strider is attached with the vibrator motor which is connected with external power supply. The switching on and off of the vibrator motor is manually controlled. The locomotion direction of the water strider can be changed by changing the position of the vibrator motor. By changing the polarity of the motor, the water strider can be made to return its path from destination to source point.

Table11. Redundancy of data for 5 trails –Simulation Vs real time testing

		Trial 1	Trail2	Trail3	Trial 4	Trail 5
Real time Testing	30 cm	58 sec	56 sec	54 sec	56 sec	56 sec
Simulation testing	30 cm	48 sec	44 sec	46 sec	46 sec	46 sec

Table12. Comparison of speed of the existing water strider with proposed one

Author	Hu et al [2]	Suhr et al [5]/son g t [6]	Zhang et al[8]	Wu et al[21]	Jiang et al[14]	Sun et al[15]	Koh et al[12]	Yan et al[16]
Speed	≈1.5 m/s (max)	<5 cm/s	≈ 1cm /s	≈10m /s	<i>Jump height: ≈ 140mm</i>	≈ 10 cm /s	Jump height: ≈ 140mm	≈ 15 cm /s

Table13. Comparison of speed of the existing water strider with proposed one

Author	Wan g et al [17]	Kin et al [18]	Kim et al [19]	Zhu et al [21]	Zhao et al [22]	Ortega-Jimenez et al [23]	Zhang et al [24]	Propose d water strider

Speed	≈3 body length hs/s	2 body length s/s	Max speed: 3.8 m/s	≈0.1 body length s/s	Max ≈30 body lengths/s	Turning rate: ≈ 200°/s	Max speed: ≈4 body lengths /s	0.5357 cm/s
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The table 11 shows the redundancy of the data taken from 5 different trails of the experiment and the mean value of the time taken in simulation is found to be 46 sec and real time fabricated testing is 56 seconds.

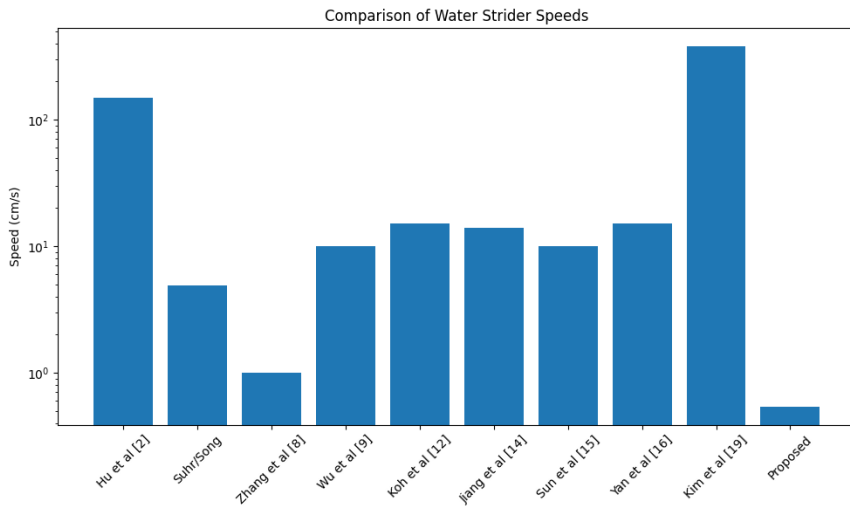


Fig 11. Comparison of the speed of the proposed water strider with that of existing one.

6 Results and discussion

This analysis 37 of articles demonstrates that bio-inspired water-walking robots are successful when hydrodynamic assistance and specialized design are balanced. From simple walkers [5] to sophisticated, quick, and multimodal soft robots [24], development has advanced. The superhydrophobic surface is essential for stability in order to avoid sinking [33]. The robots are still not as reliable or effective as the real insect, despite these developments. Reducing battery weight while delivering high power for quick actuators is one of the primary difficulties in energy storage. Actuator Speed: Selecting an actuator that is fast (like DEA) and robust (like SMA) without consuming too much power [32]. Ensuring superhydrophobic coatings remain clean and intact in dirty or harsh environments [35]. Future research will focus on autonomous swarms using simple propulsion methods like the Marangoni effect [30] for ultra-simple propulsion, further exploring applications in environmental protection, like water quality sensing and oil clean-up.

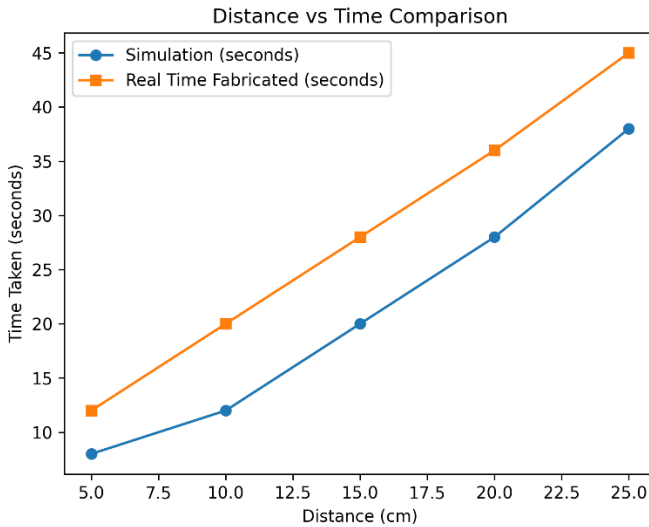


Fig. 12. Distance Vs Time taken –Simulation & Real time experiment testing

Thus the result obtained as shown in fig 11 shows that the proposed water strider has the lowest speed value when compared with other existing water strider and thus it can be used for any précised operation on the water surface. The graphical comparison as show in figure 12 shows that the simulation result is in line with that of the result from real time fabrication.

7 Conclusions

Though speed plays a vital role it is important to have a slow speed water strider which can perform any precise operation over the water surface. The main challenge remains building robots as efficient and durable as the natural insect. In this article as shown in table 12 and table 13 , the proposed water strider is found to be slow in speed and hence can be used for any precise operation on the water surface (like cleaning oil spillage on the water surface).

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