

Enhancing Transformable Drone Through Redesigned Self-Locking Joint

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Introduction



Figure 1 Example of conventional Search and Rescue drone. (Flock Safety, 2025)

Traditional Search and Rescue Operations are largely limited due to safety concerns of human rescuers. Unmanned aerial vehicle have existed to resolve such issue but faced adaptability issues, limiting large scale application of such device in SAR Operations across the globe.

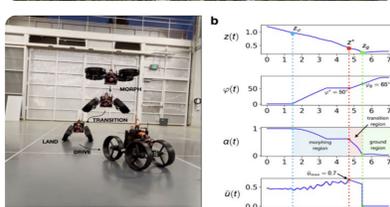


Figure 2 Aerially Transforming Morphobot. (Ioannis Mandralis et al., 2025)



Figure 3 Multi Modal Mobility Morphobot. (Sihite, E. et al, 2023)

Previous attempts focuses on the concept of Morphobot, where the UAV transforms based on its surroundings to adapt to the environment.

Figure 3 Multi Modal Mobility Morphobot. (Sihite, E. et al, 2023)

Engineering Goal

Limitations:

- Conventional drone with rigid structural design is unable to adapt to surroundings with limited clearance, tangled string/wires.
- M4's joint design with servos directly connected to joints can be easily broken through bending forces from accidents due to the highly compact design within a servo for high control precision

Engineering Goal: Support post-disaster search and rescue operations through entering regions that human rescuers are unable to reach with a transformable drone featuring an improved joint design to enhance the drone's durability while operating in hazardous areas.

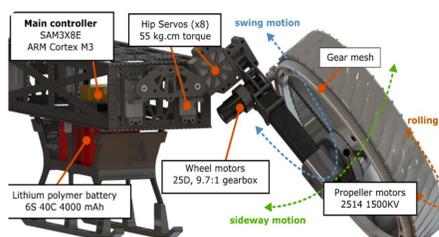


Figure 4 M4 Joint Design. (Sihite, E. et al, 2023)

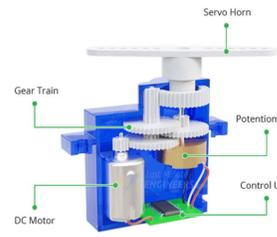


Figure 5 Servo Breakdown(Staff, 2025)

Methods

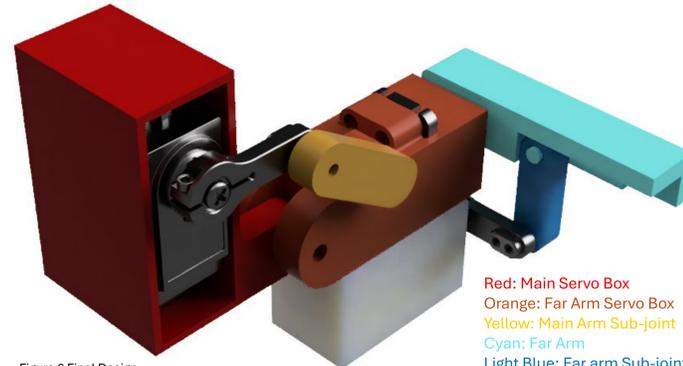


Figure 6 Final Design

Red: Main Servo Box
Orange: Far Arm Servo Box
Yellow: Main Arm Sub-joint
Cyan: Far Arm
Light Blue: Far arm Sub-joint
White: Far Arm Servo Cover

The final design of the joint system is made up of two independent joint systems. Each joint system is composed of multiple sub-joints to create a self-locking multi-link system. All the joints are screw joints to ensure structural durability compared with plastic inserts. All the main structural components are 3D printed except the arm connected to the servo as those are provided by the manufacturer for best compatibility and strength compared with custom 3D printed joints.

A total of six individual iterations are made, with four of them being redesigns of previous structure and two of them being slight improvements of current joint design. With this combination of large and small refinements focusing on different details, the final joint design is both accurate and strong, protective to electronics and ensured drone functionality in harsh environments.



Figure 7 Iteration Process

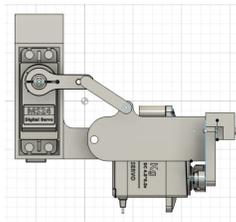


Figure 8 Main Servo Box

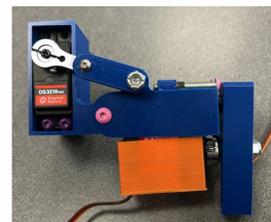
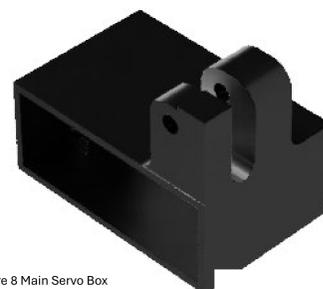


Figure 9 Far Arm Multi-link System



Figure 10 Far Arm



Each sub-component is designed and modified to reach testing goals, modifications to fillets and tolerances are individually adjusted to ensure maximum transformability, strength, without obstruction between structural components.

The overall size of the refined design is strictly limited to the original transformation size requirement for the M4, as the high adaptability of M4 came from the 8 different modes ranging from flying to crouching. The refined design is aimed to keep all 8 modes while enhancing individual joint structure through self-locked multi-link system.

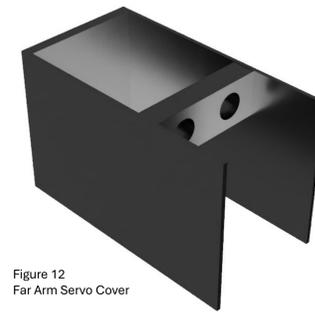


Figure 12 Far Arm Servo Cover



Figure 11 Far Arm Sub-joint

Evaluations



Figure 13 Final Device



Figure 14 Device Break Point



Figure 15 Test Setup

Iteration	Main Arm Transformability	Far Arm Transformability	Joint Strength(Main/Far)	Self-Lock Capability(Main/Far)
1.0	Not Transformable	Not fully Transformable	Strong/Weak	Locked/Unlocked
2.0	Not Transformable	Not fully Transformable	Strong/Weak	Locked/Unlocked
3.0	Not fully transformable	Transformable	Weak/Weak	Locked/Locked
4.0	Not fully transformable	Transformable	Strong/Weak	Locked/Locked
4.1	Transformable	Transformable	Strong/Strong	Locked/Locked

Table 1 Transformability Test

The iteration process is focused on three main objectives: transformability, strength, and self-lock capability. Each iteration is tested through making 3D prints once modifications are made and observations of the transformation process is the criteria of what changes should be made

Angles (degrees)	Far Arm Max Force (N)	Main Arm Max Force (N)	Control Group Max Force (N)
0	75	140	9
45	69.8	138.1	36.8
90	74.6	90	41.9
135	56.4	92.8	38

Table 2 Strength & Stability Test

The test examines the structural stability when experiencing outside force from real-world application of the arm to maximize its adaptability to dangerous environments. Experiments are focused on the movements of the arm when force is applied in different directions to analyze the structural strength and stability of the design

Angles (degrees)	Device Max Force (N)	Control Group Max Force (N)
0	45.8	5.4
45	74.5	21.6
90	111.1	9.7
135	67.4	19.7

Table 3 Instantaneous Force test

Tests are completed without servo connected to power to find the amount of force structural components is able to withstand without servo actively resisting movements. This testing method allows clear data on how much force can the structure withstand when protecting servos. Huge improvements overall with over 70% more of the forces being redirected to structural components rather than directly experienced by the servos.

Discussions

To conclude, the test result shows significant improvement in the amount of force the device can withstand without servo actively fighting against external forces. The device can achieve a self-locked state with only structural components to transmit force to rigid structures on the arm, fulfilling the main purpose of the redesigned structure—to protect servo through removing them from the process of withstanding external forces and unexpected arm movement due to accidents. Future works to this self-locked multi-link joint system includes using more rigid material and manufacturing technique rather than PLA with 3D printing. The strength of each individual structural component is the current limitation to the amount of force the device is able to withstand. Other improvements include minimizing sub-joint size to further shrink space requirements for each joint system. Current design proves the functionality of self-locking joint structure in transformable drone; an improved self-locking joint can further redirect force from servo to other device structures.

References

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Figure 6-14 Created by Yicheng Shao

Table 1-3 Created by Yicheng Shao