Armasuisse W+T
Herr Dr. Mark Höpflinger
Feuerwerkerstrasse 39
3602 Thun

Offer Nr.	**2023-10-19**
Valid until:	30 April 2024
Payment terms:	Within 30 days without deductions

Dear Dr. Höpflinger,

We gladly offer you our services for an applied research project with the title **'Passively morphing drone for small gap traversal'**.

Amount/ Units	Description	Amount [CHF]
1	Applied research project **'Passively morphing drone for small gap traversal'**	50'000.00
Total		**50'000.00**

Passively morphing drone for small gap traversal

Aerial robotics is an already well established, but still quickly growing field in research. Between the multitude of problems that can be solved with a flying drone are tasks of exploration and inspection in areas unsafe or inaccessible to humans. When these areas lie indoors or in otherwise tightly enclosed environments, it can become necessary for a drone to traverse small gaps. Gap is relatively speaking easy to accomplish, but it does bring with it a design trade-off. The drone needs to be small enough to fit trough the gap, but at the same time it is well known that drones with large propellers are more efficient and thus offer longer flight times.

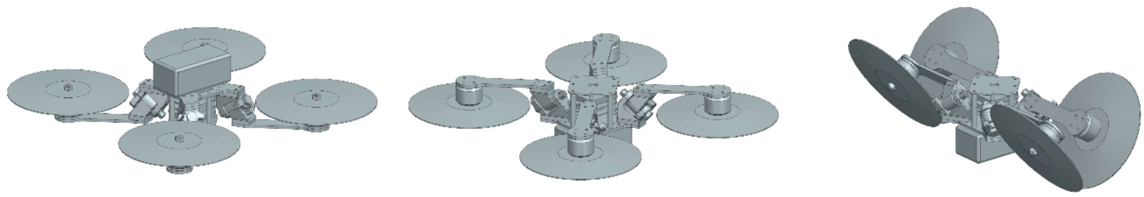
The aim of this project is to sidestep the gap size vs. flight time trade-off by exploring a novel morphing drone design. A design where the drone can, temporarily and on command, morph into a smaller and less efficient shape to easily traverse a gap. Although, morphing drone designs do not typically come for free. If additional actuators for morphing are needed, then the trade-off is simply shifted to an increase in complexity/weight. To truly sidestep the gap size vs. flight time trade-off, the here proposed morphing design does not feature any additional actuators and only a very limited increase in complexity. Still, the design is expected to reach ~50% in width reduction in exchange for some temporary efficiency loss. An accomplishment that hasn't been reached before.

	small gap traversal	high flight efficiency	low complexity
Typical large multicopter	-	+	+ +
Typical small multicopter	+	-	+ +
Typical morphing multicopter	+	+	-
Proposed novel multicopter	+	+	+

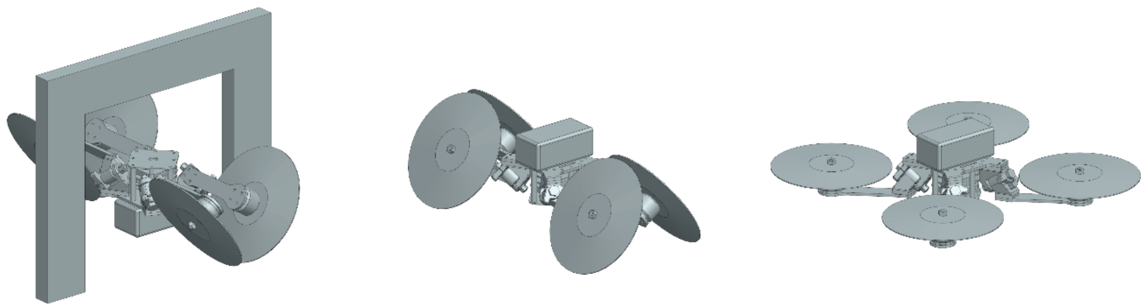
Design Concept

The here proposed design is very similar to that of an ordinary quadcopter. In fact, the only differences are a slightly more involved flight controller and a hinge on each arm, where the morphing happens. Each hinge has two mechanical limits on its rotation, corresponding to a morphed respectively un-morphed configuration, with the hinge being completely free to rotate between them. What makes this design work is a careful choice of the hinge axis and the limit angles.

When the drone is flying in its un-morphed configuration (like an ordinary quadcopter), the trust of the propellers pushes the hinges against one of their limits, preventing movement of the arms and allowing for normal operation of the drone. If a small gap needs to be traversed, then the drone flips 180° on its head, inverting the propeller spin to keep flying. In this state the torque acting on the hinges is reversed, and the arms move from one limit position to the other. The hinge axis is chosen such that when the arms reach their second limit, they still lie on the same plane but are moved closer together and rotated by ~60°. This results in a vastly narrower, albeit more inefficient, morphed drone.



1: Approach gap 2: Flip 3: Passively morph



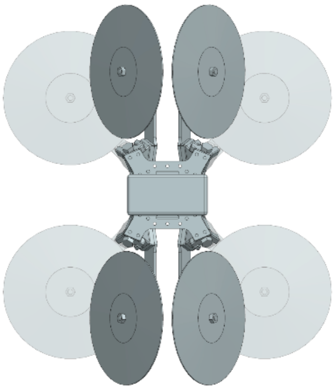
4: Traverse gap 5: Un-flip 6: Passively un-morph

Relation to existing work

To put this new design in the context of existing morphing drones for gap traversal, a new metric is presented. $X_c = L_1/(2.25 \cdot d)$ describes the proportion between the morphed width of the drone L_1 and the width of an equivalent compact non-morphing drone $(2.25 \cdot d)$ with the same propeller diameter d. It is argued that X_c is more relevant than the more commonly used metric $X_m = L_1/L_0$, with L_0 the un-morphed width. As for example, a very large morphing drone with small propellers should not be valued higher that an equivalent compact non-morphing drone, if the morphing drone can not morph below the size of the non-morphing drone, simply because the non-morphing drone could already traverse the same gaps. Morphing in dimensions other than in width, although useful in some cases, is not considered for this project.

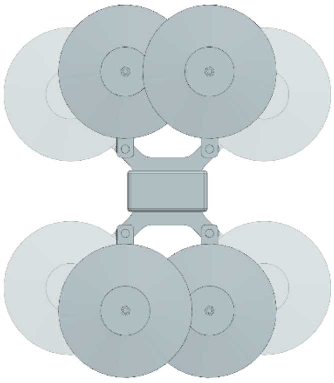
Proposed novel quadcopter

$\boldsymbol{X_c = 51\%, X_m = 47\%}$



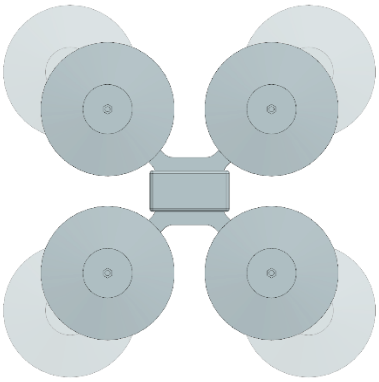
Example pivoting quadcopter

$X_c = 73\%, X_m = 67\%$



Example contracting quadcopter

$X_c = 100\%, X_m = 80\%$

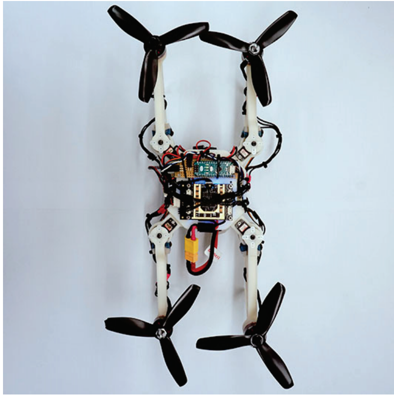


Bucki et. al, 2019

$X_c \approx 44\%, X_m \approx 45\%$

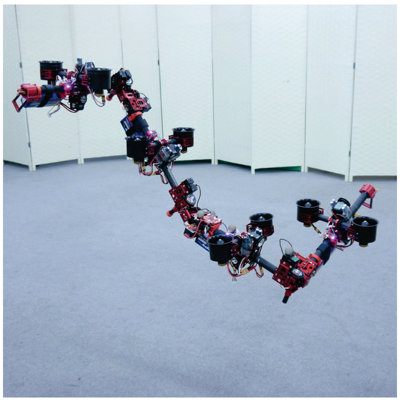
Falanga et. al, 2018

$X_c \approx 80\%, X_m \approx 62\%$



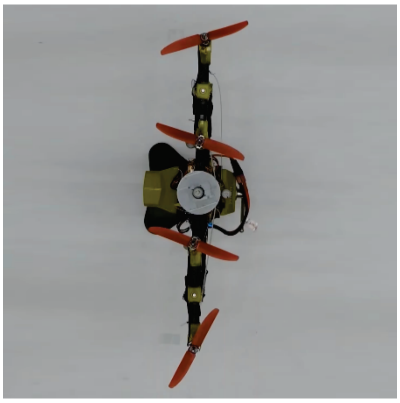
Zhao et. al, 2018

$X_c > 100\%, X_m = ?\%$



Riviere et. al, 2018

$X_c \approx 44\%, X_m \approx 44\%$

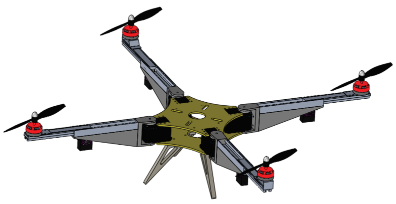


Zhao et. al, 2017

$X_c > 44\%, X_m = ?\%$

Derrouaoui et. al, 2021

$X_c \approx 86\%, X_m \approx 46\%$



The table above shows the morphing capabilities of the latest morphing drones build primarily or secondarily for gap traversal. Out of these only Buckie (2019) is a passively morphing design, with all others being actuated by additional motors. Buckie (2019) and Riviere (2018) are furthermore designs that are unstable when morphed, requiring a run-up to traverse short gaps. This study shows the uniqueness of the proposed design in managing to reach an exceptionally low morphing ratio X_c, while still being controllable, and without requiring additional actuators.

Preliminary Study

To show the feasibility of this project a first scale prototype was built. A simple drone was constructed using racing drone components and featuring 3D printed arm pivots as described in the concept. Due to its basic controller and other minor shortcomings this drone is not able to transition between its morphing configurations, nor is it able to control its position accurately enough to traverse a gap. Nevertheless, it shows that such a drone can remain stable and controllable in both its morphed and un-morphed configuration, indicating that transition and gap traversal are likely feasible.

Un-morphed flight:	https://www.youtube.com/watch?v=kBgZJ2vg6Nk
Morphed flight:	https://www.youtube.com/watch?v=3At2thakIoE
Morphing animation:	https://www.youtube.com/watch?v=84m2BL9D53c

Annual Programme

In the period April 2024 – November 2024, project engineers from the Institute for Photonics and Robotics (IPR) at the Graubünden University of Applied Sciences (FHGR) will work on the project's work packages. A showcase of the interim results will be presented at the "Advanced Robotic Capabilities for Hazardous Environments” ARCHE event in July 2024.

Work Packages

Package 1: Mechanics

- Integration of a PX4 capable flight-controller.
- Integration of sensors for pose estimation and navigation.
- Building of iterative prototypes based on future learnings.

Package 2: Control

- Implementation of a configuration switcher (mixer, tuning, etc.).
- Implementation of a transition controller to flip drone.
- Implementation of a position controller and navigator for gap traversal.

Package 3: Testing & Validation

- Tuning of controller parameters for precise pose tracking.
- Validation of the transition controller on the drone.
- Showcase of morphing combined with gap traversal.

Payment appropriations

CHF 50‘000.- (including any VAT)

Payment plan

CHF 50‘000.- according to the invoice from FHGR

We hope that this proposal fits your expectations, and we would be happy to carry it out for you.

Best Regards,

Marco Ruggia
Researcher and Lecturer

Christian Bermes
Director of studies

Institute for Photonics and Robotics (IPR)
University of Applied Sciences of the Grison (FHGR)
Switzerland