Liu, J., Yik, W., Saw, B. and Hesse, H. (2022) Perching Drones for Distributed Communication Systems in IoT Applications. In: 2022 IEEE 8th World Forum on Internet of Things (WF-IoT), Yokohama, Japan, 26 Oct - 11 Nov 2022, ISBN 9781665491532 (doi: 10.1109/wf-iot54382.2022.10152182)

# Perching Drones for Distributed Communication Systems in IoT Applications

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***Abstract*—A major limitation to using drones for IoT applications is the limited flight time. What if drones could operate without the need to land or return to home for recharging? This paper presents a perching concept for multirotor drones which allows them to operate as perpetual sensor or communication hubs in remote or urban areas. Unlike existing concepts of perching drones which rely on grasping mechanism and spikes, the proposed concept uses electro-permanent magnets (EPM) to attach to ferrous surfaces. EPMs are small, lightweight and can hold up to 15kg potentially enabling the perching of heavy-lifting drones. Similar to electromagnetic door locks, EPMs can be charged and discharged with a small power supply operating at 5V which is suitable for a range of multirotor vehicles. The paper experimentally demonstrates the perching concept for horizontal and vertical surfaces in manual flight and provides a control strategy to enable autonomous perching manoeuvres.**

***Keywords—aerial robotics, airborne sensors, unmanned aerial vehicles, perching.***

## I. INTRODUCTION

Unmanned Aerial Vehicles (UAVs) have become a popular choice over the years for a variety of applications such as surveillance, inspections, imaging, communication, or even emergency response situations [1]-[3]. With the advancement in the Internet of Things (IoT) and drone technologies, the applicability of UAVs has become more extensive. A mobile wireless data collection and transmission network for specific purposes can be formed by utilizing UAVs as a transport medium carrying IoT devices and deploying them to desired locations [4]-[6]. In addition, features such as ease of deployment, ability to access hard-to-reach areas and cost-effectiveness enable them to replace the conventional workforce in various sectors.

Though multirotor UAVs have many key advantages, limited battery life is a significant factor that is hindering the full potential of UAV applications. As most UAVs are powered by onboard batteries, their operation time is restricted by the limited specific capacity of LiPo batteries typically used in UAVs. To maximize the UAV operation time, it is critical to consider the power consumption of the UAV and plan missions with an energy-efficient approach such that power consumption is optimized [6]-[9]. Alternatively, we can incorporate the flight time as a key parameter in design methodologies for UAVs [10]-[11]. However, the UAV flight time remains a major hurdle for the effective use in IoT applications and more efficient solutions should be explored.

Mimicking bird or insect behaviour, perching emerges as a promising solution whereby the UAV lands or attaches to objects while not flying. This allows the vehicle to attach to a surrounding structure and power off its battery draining propulsion system. While attached, the onboard equipment can continue to perform assigned tasks over an extended time, making long-term data collection or transmission feasible. Perching UAVs can also operate in weather conditions that would make flying difficult. This enables operation in disaster situations, as proposed in [3]. The UAV can perch for hours or days, providing critical communication infrastructure and when needed power on its propulsion system to return to base for charging or fly to the next site for further data collection.

### A. Related Work

Numerous studies have demonstrated the concept of perching tailored to specific surface types and UAV designs. Concepts for flapping fliers typically mimic techniques used by birds to perch on elevated surfaces [12]. Multirotor concepts focus instead on insect or bird-like capabilities to attach to horizontal or vertical surfaces. Several perching mechanisms have been explored in recent years and can be summarised in the following three categories [13]:

- *Grasping-Based Perching Mechanisms.* This approach allows multirotor UAVs to grasp to surfaces similar to birds perching on tree branches or power cables. For example, [14] developed an avian-inspired, passive perching mechanism for UAVs using two compliant, underactuated claws and two folding legs.
- *Embedding-Based Perching Mechanisms.* Inspired by insects, this mechanism enables UAVs to perch to rough surfaces using spines or micro hooks. For example, studies in [15]-[17] utilized hook-shaped micro-spines to interlock with asperities on vertical rough outdoor surfaces.
- *Attaching-Based Perching Mechanisms.* This approach enables perching to flat surfaces. Proposed attachment systems include magnets, dry adhesives, electrostatic adhesives, and vacuum cups. For example, [18]-[20] used dry adhesives grippers for the perching and [21]-[22] demonstrated the use of suction cups to perch on smooth surfaces.

Fig 1. Concept of Perching UAV for urban scenarios.

Although all these methods are capable of powerless perching, the aerial vehicle requires high-level precision control and mechanical robustness for strong impacts to perform an aggressive aerial manoeuvre to align the gripper with the surface and generate enough force to engage the perching mechanism to attach to vertical surfaces. Additionally, these perching mechanisms are difficult to implement in real-world scenarios. Micro-spines will damage the surface, and suction cups and dry adhesives lose their grasping power over time, making them unreliable for repeated perching.

The primary focus of this work is to develop a concept for a UAV with a perching mechanism that is applicable to real-world scenarios. As such, magnets would be a feasible solution in urban or industrial environments where ferrous surfaces are abundant. By utilizing magnets, UAVs can perch on lamp posts, bridges, and metal frames, for example, for traffic surveillance and inspection tasks. It also enables the UAV to achieve repeated perching without performing an aggressive manoeuvre and damaging the surface, compared to other proposed perching mechanism surveyed in [13].

Perching using magnets has been explored previously. Studies in [23]-[24] use permanent magnets to easily attach the vehicle to the ceiling. However, to detach these mechanisms, a large force is required to disconnect the permanent magnet from the surface, e.g. [24] proposes a magnetic hand which can actuate to detach the magnet from the surface. Compared to permanent magnets, an electro-permanent magnet (EPM) would be a better option. EPMs do not require integration with a complex mechanism to produce a force for detachment. They can switch between magnetized and de-magnetized states using simple control inputs, granting complete user control, and thus enabling fully autonomous perching operations.

### B. *Objectives*

The primary objective is to design and develop a UAV with a simple EPM perching mechanism that can attach and take off from vertical and horizontal ferrous surfaces. This work also aims to address the problem of relying on aggressive manoeuvre, impact, and complex mechanisms for perching by proposing a new perching strategy. The system allows the implementation of distributed UAV swarms with largely extended operation time, for example, to enable IoT sensors nodes, communication capabilities or communication hubs as presented in Fig 1.

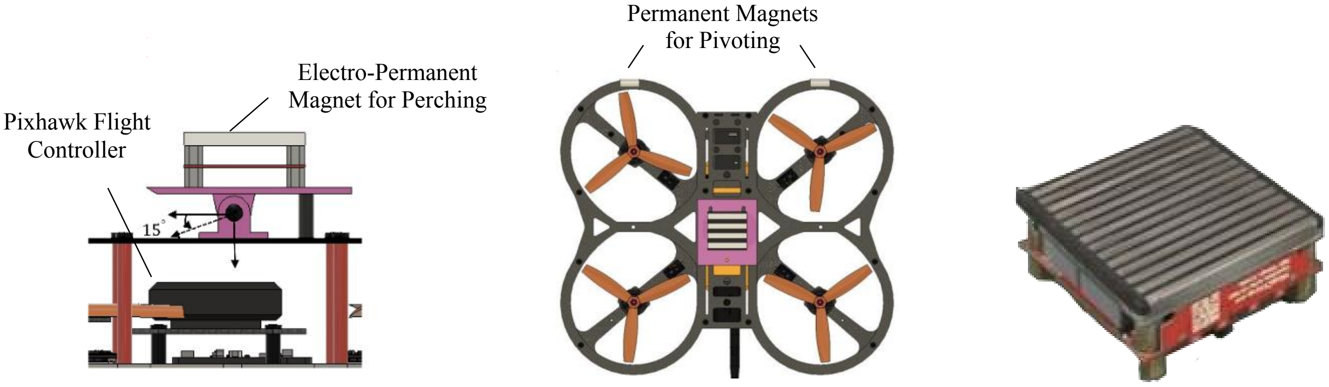
## II. PERCHING CONCEPT (DESIGN & STRATEGY)

In this section we first present the system overview of the UAV used to develop the perching mechanism.

### A. *Aerial Platform*

Our aerial platform is a compact and lightweight medium-sized quadcopter that consists of a 250mm caged modular carbon-fibre frame as shown in Fig. 2. The caged design keeps the propellers within the structure preventing the propellers from hitting any objects. Moreover, this critical feature shields onboard components, enabling the UAV to operate safely around walls. This platform is equipped with Pixhawk Mini flight controller, which has advanced onboard sensors and multiple connection ports to provide better flight controls and support additional peripherals.

Summing the weight of other onboard components such as the GPS module, RC receiver, three cell Lithium-Polymer (LiPo) battery, electronic speed controllers, and motors, the total weight of the UAV is estimated to be 900g. Based on the frame size and estimated weight, 5-inch three-bladed propeller and 2300Kv motor were chosen. Using this combination, each motor is capable of producing 700gf of thrust (thrust stand experiments not shown here for brevity). With a total thrust of 2.8kg produced by all the motors, the minimum requirement of a 2:1 thrust-to-weight ratio is satisfied [11] and allows for more components to be added for future automation.



(a) Side View of UAV.   (b) Top View of UAV.   (c) Nicadrone Electro-Permanent Magnet.

Fig. 2. Schematic of UAV with EPM mechanism.

### B. *Nicadrone Electro-Permanent Magnet*

The Nicadrone EPM shown in Fig. 2(c) was selected as the primary gripper, allowing the drone to perch. The EPM is small with a surface area of 16cm$^2$ and weight of 100g making it ideal for UAV applications. The magnet is integrated in the design with a Pixhawk Mini fight controller via UAVCAN connection and is controlled by Pulse Width Modulation (PWM) signal from the remote controller.

The EPM has three switchable operation modes, magnetized, neutral, and demagnetized. To achieve full magnetization, the capacitor with wire winding within the magnet is charged three times to create a strong magnetic field enabling it to support up to 15kg of payload. This provides capabilities to use the same EPM for larger UAVs than demonstrated in this work. EPMs consist of a composition of magnetic material with high and low coercivity. The EPM is magnetised through an electric current which aligns the direction of magnetisation of both components. Unlike conventional electromagnets, which require high power to maintain magnetisation, EPMs can retain the magnetized state over long periods even when there is no current supplied to it. In practice, this implies that the UAV can be entirely disconnected from the power source and stay attached a ferrous surface for an extended range (several days was achieved for the proposed mechanism). When the operator triggers the command to release the UAV, the EPM is demagnetized through a reverse current. The capacitor is then charged and discharged several times to change the direction of the magnetic field to degauss.

The UAV is fully sensorised through the Pixhawk Mini flight controller unit (FCU) which uses inbuilt inertial sensors and a magnetometer to control the vehicle during flight. While magnetic interference was a concern, the EPM was mounted far away from the FCU and the state estimation was not affected by the EPM operation.

### C. *Perching Mechanism Design*

This section presents the mechanism design developed for UAVs to attach to horizontal or vertical ferrous surfaces. As shown in Fig. 2 the developed perching mechanism is achieved by installing the EPM on a 3D-printed self-tiltable platform mounted in the centre of the UAV. This platform is designed to rely on the UAV weight to align the EPM with horizontal or vertical surfaces for perching instead of utilizing external actuation. The centre of gravity is shifted forward, and the weight of the EPM causes the platform to be back heavy and lean backward to rest on the aluminium spacer underneath to stay levelled for horizontal surface attachment.

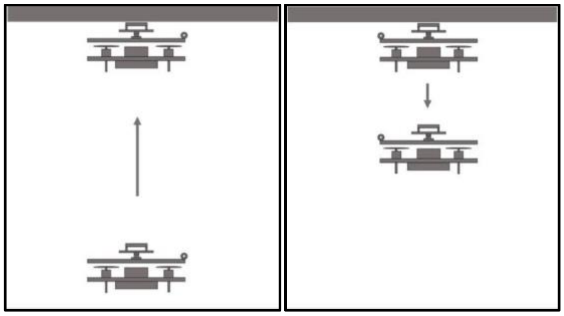


Fig. 3. Perching concept for horizontal surfaces: Perching (left) and release manoeuvre (right)

To align with a vertical surface, the UAV requires to perform a simple pitch forward motion. This motion and weight of the EPM cause the platform to lean forward, and the leaning angle is restricted to 15° by a string (not shown in Figure). The cylindrical permanent magnet with an outer diameter of 7.5mm and 25mm thickness can lift 300g of payload using its lateral side. Two magnets are mounted at the front of the outer frame of the UAV. They are coated with a layer of rubber sleeve to provide friction force to prevent sliding on smooth surfaces and serve as a pivot for vertical surface perching manoeuvre.

### D. *Perching Concept – Horizontal Surface*

Perching manoeuvre on a horizontal surface or ceiling is straightforward as illustrated in Fig. 3. The UAV flies up directly to the target surface with EPM magnetised to attach to the top and perch. The EPM provides sufficient grasping force to sustain the UAV weight. To release the vehicle, the UAV turns on its motor to generate sufficient thrust that allows it to hover and demagnetize the EPM to fly away from the ceiling.

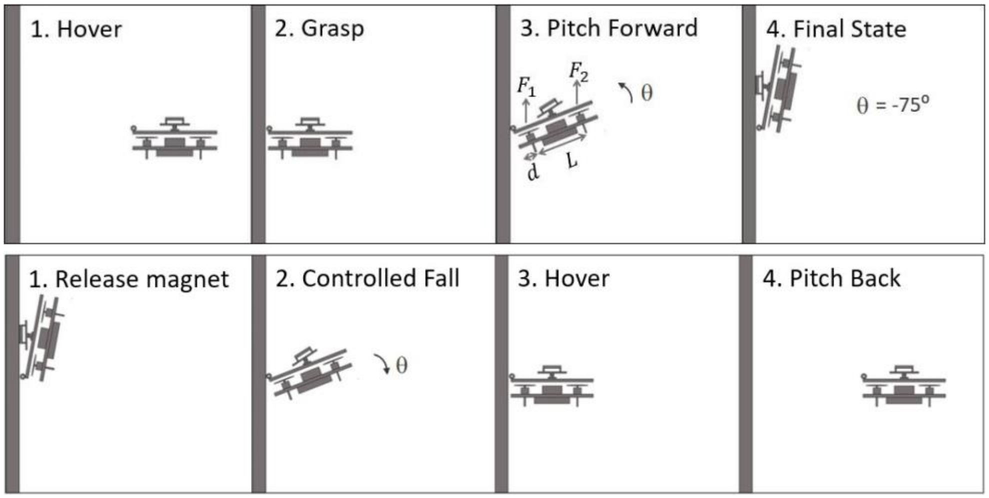


Fig. 4. Perching concept for vertical surfaces: Perching sequence (top) and Release sequence (bottom).

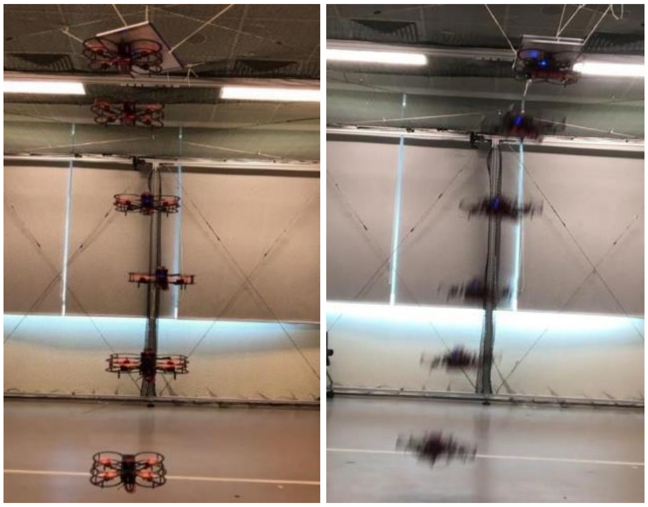


Fig. 5. Experimental demonstration of perching manoeuvre on horizontal surfaces: Perching (left) and Release (right).

### E. *Perching Concept – Vertical Surfaces*

The proposed perching manoeuvre for vertical surfaces, as illustrates in Fig. 4, is more challenging and relies on a simple pitch forward motion which consists of four main steps.

i. Hover: The UAV with magnetized EPM hovers at the desired height and moves towards the target surface at a controlled speed.

ii. Grasp: When the UAV contacts the surface, the front-mounted permanent magnets secure the UAV at its current position. The small holding force of 300g of the permanent magnets ensure that the vehicle is constrained in its translational motion but can pitch around its pitching axis.

iii. Pitch Forward: The UAV then perform a pitch forward motion controlled by the pilot and pivots on the permanent magnets to perch onto the vertical surface using the EPM. During this manoeuvre, the mounting plate parallels the EPM with the surface by tilting 15°.

iv. Perching State: Finally, the drone is perched at a leaning angle of $-75°$ and the motors/system can be turned to perform its intended application.

Once the intended task is completed, the drone returns to aerial mode by performing a controlled release manoeuvre. The EPM is demagnetised, and the UAV pitches backward while pivoting on the permanent magnet. During the fall, the thrust produced by the motor and propeller is increased by raising the throttle level to counter the momentum. Lastly, a small rearward pitch motion is required to detach the permanent magnet from the surface and the UAV can return to its hover position.

## III. EXPERIMENTAL RESULTS

In this section we first demonstrate the experimental implementation of the proposed perching approach. As shown in Fig. 5, the simple perching and release manoeuvre to horizontal surfaces can be easily achieved with the proposed perching design. The UAV can attach to the metal plate while hovering. During the release operation the flight controller ensures that the vehicle gently detaches when the EPM is demagnetised.

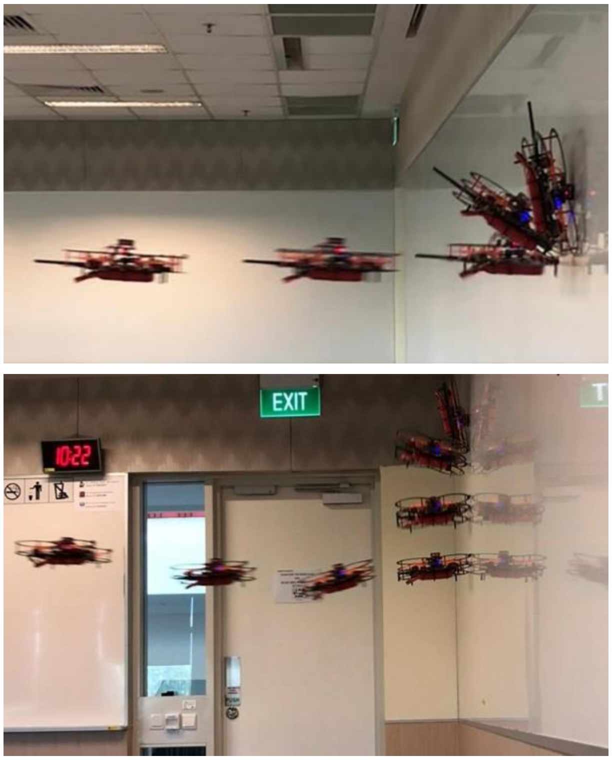
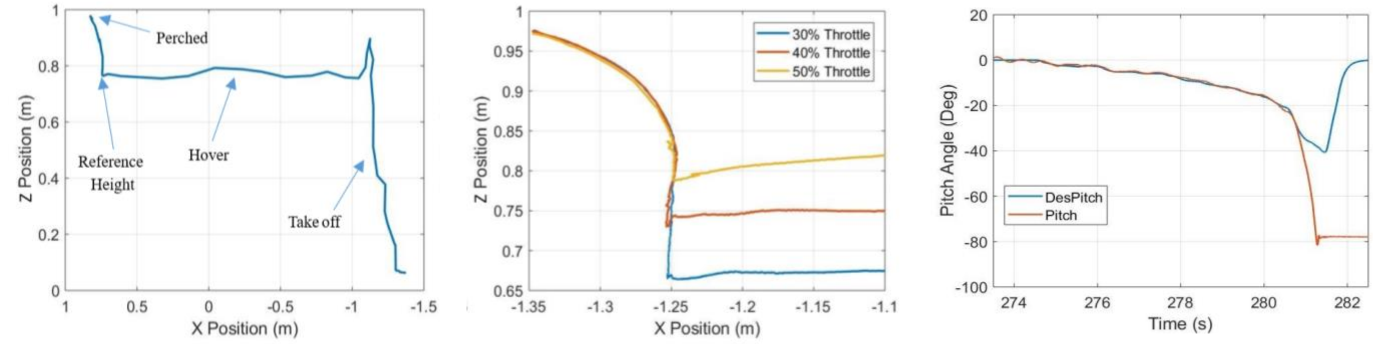


Fig. 6. Experimental demonstration of perching manoeuvre on vertical surfaces: Perching (top) and Release (bottom).

Fig. 6 presents the snapshots of the perching approach to vertical surfaces. The perching manoeuvre requires a pitching motion for the EPM to attach to the surface. During this complex manoeuvre, the vehicle is fixed by the permanent magnets which provide the pivot. However, during the release operation for vertical surfaces, it can be observed that the UAV tends to drop in altitude when detaching from the wall. The proposed strategy uses no active release mechanisms and instead requires the vehicle to fall backward after EPM is demagnetized, and for the pilot to gradually increases the throttle level. The thrust produced by the propulsion system is insufficient the counterbalance the immediate downward acceleration resulting in a drop in altitude. Nonetheless, if sufficient ground clearance is provided (at least 1m), the UAV is able to maintain airborne and successfully detach from vertical surfaces as presented in the next section.

### A. *Trajectory Data using Optitrack*

The concept of our proposed perching strategy has been demonstrated in the Aerial Robotics Lab. To explore the dynamics of the vehicle during the perching approaches to horizontal and vertical surfaces, the Optitrack motion capture system was used to record the vehicle position and orientation. The trajectory data in Fig. 7 is presented for the scenario of vertical surfaces only as this is the more aggressive approach while the horizontal approach requires no pitching of the vehicle during approach/release.



(a) Perching approach from take-off. (b) Effect of throttle setting during release. (c) Minimum Pitch Angle.

Fig. 7. Trajectory data for perching experiments against vertical surfaces obtained using OptiTrack.

The entire sequence of perching from take-off to attachment at the vertical surface is shown in Fig. 7(a). It can be seen that the vehicle is able to perch successfully at the reference height of 0.78m as indicated in the figure. The eventual increase in altitude is the result of the pitching motion resulting in the vehicle centre point to move to almost 1m altitude. The trajectory data for the release manoeuvre is shown in Fig. 7(b) to explore the amount of throttle required during release to prevent the drop in altitude. Three release attempts have been recorded using OptiTrack for a 30%, 40% and 50% increase in throttle during the fall. A reference height of 0.78m was selected from the prior successful perching attempt (discussed above). It is shown that using 30% and 40% throttle results in a decrease in altitude of 0.05 m and 0.1 m, respectively, while 50% throttle is able to the maintain the altitude. These flight test results are specific to the quadcopter configuration piloted manually. But the results demonstrate that it is possible to fly the release repeatedly with minimal drops in altitude.

Finally, we explore the pitch input required for the UAV to successful attach to vertical surfaces during the perching approach. Fig. 7(c) presents the pitch data from a successful perching manoeuvre comparing the estimated pitch orientation (red) versus the commanded pilot input (DesPitch in blue) obtained from the Pixhawk flight log data. Based on the data for several flight tests, it is found that the UAV requires a minimum forward pitch angle of $-35°$ to perform a successful perching manoeuvre on a vertical surface. As shown in Fig. 7(c), the commanded pitch angle (DesPitch) controlled by the pilot is slowly increased until the drone is perched. At DesPitch of $-35°$, the graph shows that the vehicle has successfully attached which is indicated by the sudden increase to $-75°$. The overshoot to $-80°$ was due to the impact created when the EPM contacts the surface. While a commanded pitch angle of 35° is fairly aggressive during free flight (found during drone racing), for the proposed perching strategy the vehicle is already secured with the permanent magnets acting as a pivot point. Hence, we were able to repeatedly fly the perching and release manoeuvres for horizontal and vertical surfaces without any crashes.

## IV. DISCUSSION

The proposed perching concept has been proven in numerous flight experiments to provide a reliable sensor platform for IoT applications. In this section we will discuss the benefits of using the perching concept over conventional UAV operations and provide some thoughts on design improvements and the potential for automation.

### *A. Extended Flight Time for IoT Applications*

With a weight of approx. 100g, the Nicadrone EPM enables the integration of the proposed perching concepts to small scale drones with a maximum take-off weight of at least 300g. This estimate provides a good lower weight boundary (assuming that 30% of the maximum take-off weight is payload [11]), but it neglects the weight of any additional payload for sensors specific to the IoT application. The Nicadrone EPM runs on 5V which can be integrated directly with the UAV power supply using at least a 2S system with 7.4V nominal voltage. The EPM itself only requires 1s of charge to magnetise the pad resulting in a small power requirement for the perching manoeuvre (compared to the propulsion system requirements). Once the EPM is magnetised and the vehicle has attached to the ferrous surface, the system can be turned off completely with practically zero power consumption during the perching operation (neglecting the power requirements for the IoT application). This has been tested in the lab with the vehicle attaching to the vertical or horizontal surfaces for several days. Hence, perpetual perching operation can be achieved with this approach.

The attachment of the UAV to surfaces depends on the surface quality/condition (e.g. dirt, paint, corrosion) and shape (flat surfaces) of the ferrous surface area. This introduces some limitations for the proposed design, but for the proposed IoT applications in urban/industrial areas, it is not restrictive to identify potential perching areas.

### *B. Design Consideration*

The proposed design enables a flexible perching mechanism which allows attachment to vertical and horizontal surfaces. While the concept of perching to horizontal surfaces can be easily achieved with an upward-facing EPM, the design provides the benefits to also perch against vertical surfaces. This is achieved by significantly aggressive pitch manoeuvres of up to 35° pitch inputs. Improved designs can consider an additional forward-facing EPM (not shown here). The friction of the EPM against vertical surfaces (potentially increased with a rubber pad) is sufficient for the UAV to hold its height. For larger vehicles it is then recommended to use two EPMs, one upward-facing for horizontal surfaces and another forward-facing for vertical surfaces. This eliminates the need for the pitching manoeuvre and the pivot point achieved with the permanent magnet. However, the additional EPM adds more weight to the vehicle. Hence, the proposed design in this paper provides a versatile solution for lightweight UAVs using a single EPM to achieve perching against both vertical and horizontal surfaces. This can be attractive to enable the use of cheap, miniature UAVs as sensors nodes in IoT applications.

## V. CONCLUSION

In this work we have presented a novel concept of a perching drone which is able to attach against horizontal and vertical surfaces. Taking advantage of electro-permanent magnets (EPMs), the drone can perch against ferrous surfaces for days/weeks with zero power requirements to remain attached. Hence, the proposed aerial platforms can be used to develop sensor hubs in inaccessible areas, e.g. in warehouses, urban or disaster areas, for novel IoT applications. Unlike other perching concepts which require heavy mechanical actuators or temporary adhesives, the proposed concept provides a reliable, long-lasting perching solution which has been demonstrated in real-world scenarios. While a simple concept with two EPMs can be considered for heavier drones, the proposed perching manoeuvre enables perching to both vertical and horizontal surfaces using a single EPM allowing for cheap, lightweight flying sensors as light as 300g. The potential use cases for such airborne sensors enable novel IoT applications for drone-based communication, surveillance, and monitoring hubs.

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