# Autonomous landing on pipes using soft gripper for inspection and maintenance in outdoor environments

P. Ramon-Soria, A.E. Gomez-Tamm, F.J. Garcia-Rubiales, B.C. Arrue and A. Ollero

***Abstract*—The use of unmanned aerial systems for industrial applications has evolved considerably in recent years. This paper presents an aerial system capable of perching autonomously on pipes for inspection and maintenance in industrial environments. The target pipe to perch on is detected using a visual algorithm based on a semantic convolutional neuronal network. The information from a color camera is used to segment the image. Then, the segmentation information is fused with a depth image to estimate the pipe's pose, so that the pose of the robot can be controlled relative to it. The aerial robot is equipped with a soft landing system that robustly attaches it to the pipe. The article presents the complete development of the system. Experimental results performed in outdoor environments are shown.**

***Index Terms*—UAVs, autonomous landing, inspection, soft robotics, CNN**

## I. Introduction

AERIAL robots are a trendy research field nowadays. Researchers are constantly looking for new applications for these platforms. In this scenario, refineries are a potential client that must be taken into consideration. These companies invest yearly thousand of dollars for the inspection and maintenance of their pipe networks. These tasks are not only a waste of money, but also have a high human risk.

Developing a system capable of replacing the classic inspection methods is non-trivial. The first step is the development of a robust aerial system that ensures repeatability. It must support enough payload to hold all the sensors needed for the mission, but being as small as possible so that the maneuverability in the refineries is guaranteed.

For this mission, a custom platform has been built using a DJI F550 frame. In order to automate the behavior of the aerial robot, an onboard computer has been built-in, and an Intel realsense D435 camera has been chosen as the main sensor. This device offers a good trade-off between weight and quality of data in outdoor environments. Finally, the robot has a customized landing system to perch on the pipes. This landing system is 3D printed using soft materials and covered with silicone.

The idea behind the landing system is to give the unmanned aerial vehicle (UAV) soft robotics properties. This has two principal advantages. At first, soft robotic systems are safer for the interaction with the environment when attaching or perching. Thanks to their properties, interactions with the pipes are less harming compared to rigid mechanic perching mechanisms. Additionally, this system allows a better adaptation to many pipe's diameters thanks to its ability to bend and hug the pipe.

The remainder of this paper is organized as follows: Section II introduces the state of art of all the related systems. After that, section III describes the system, taking emphasis on the aerial platform, the soft gripper, the pipe detection algorithm, and the visual guidance control. Section IV shows the experimental validation. Finally, Section V shows the conclusions obtained and the possible future research lines of this application.

## II. Related Work

The research presented in this paper has been carried out under the framework of the European Project HYFLIERS. This project aims to develop an automated aerial system for inspection of pipes using unmanned aerial vehicles (UAVs). The development of autonomous landing systems capable of perching on narrow objects is still a challenging line of research in the aerial robotics field.

These approaches typically rely on visual devices such as cameras. The problem of locating the landing place is commonly solved using image patterns, which are easier to locate [1], [2], [3], [4]. Nevertheless, these solutions do not apply for this paper, because it is not reasonable to place landmarks in every pipe, and aside from that, the purpose is to inspect the bare surface of them.

Other researchers explored different techniques for the inspection of power lines and gas pipes [5], [6], [7], [8], [9], [10], [11]. These authors rely on the use of classic detection methods, such as Hough transforms, or laser sensors.

The idea behind all these researches is to develop solutions for industrial facilities to reduce the maintenance costs, and also avoid risks for their employees.

This article proposes the use of a convolutional neural network (CNN) for semantic segmentation. Giving the right training, CNNs have been proved to be incredibly robust to changes in illumination and scenarios, reducing the chances of false positives and negatives.

However, it is well known that CNN, and particularly segmentation networks such as SegNet [12] or DeepLab [13], usually have an elevated computational cost and requirements for specific hardware to boost their usage. This fact is even more critical while working with UAVs due to the strict payload constraints and the vital necessity of getting control measurements in real-time. To overcome this issue, the use of Shuffleseg [14] is proposed. This CNN offers real-time semantic segmentation. For the problem stated in this article, only two categories are used, the background and the pipes. Additionally, in order to be able to run CNNs efficiently in the aerial platform, a Jetson TX2 onboard computer is used.

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The HYFLIERS project also focuses on the use of aerial manipulators. This technology has greatly evolved in recent years [15] one example is the ARCAS [16] project where the idea was to develop unmanned aerial systems capable of carrying robotics arms and other tools to enable UAVs to manipulate in inaccessible places. Another approach using helicopters was explored in [17] focusing on the design of mechanical hands for grasping and perching. In the last years, aerial manipulation has turned towards to achieve dexterous manipulation skills. In AEROARMS project [18], multirotors are equipped with two arms to carry out more complex tasks. All these researches have guided the development of the UAV presented in this paper.

Using manipulators for attaching to a surface is still challenging nowadays. Authors in [19] developed a drone which stuck to magnetic surfaces in refineries. This system is intended to replace the wall crawlers developed in recent years with aerial systems that use electromagnets to get stuck to the pipes. These allow the drone to carry out inspection, performing ultrasonic and corrosion testing. This solution has the same goal as the one presented in this work, the development of a platform capable of land or get adhered on pipes and perform different tests. Nevertheless, their assumption of ferromagnetic pipes hinder the generalization of the platforms and this assumption cannot be guaranteed in all the environments or types of pipes. For that reason, this paper proposes the use of a soft gripper that is able to adapt to the pipe's size and capable of landing on any material.

The system detailed in this paper presents a new form of developing landing systems based on soft robotics. Similar approaches have been tried out in the past, such as semi-soft landing systems [20], as well as others with claws to achieve grasping [21]. These bio-inspired approaches are naturally efficient. However, these previous works focus only on the landing system, obviating the integration with the whole framework.

Finally, it is worth to mention the control systems or visual guidance. The reliability of control has always been a significant concern in UAVs development. Approaches with different types of systems and control solutions have been studied. The application of PID control and the use of extended Kalman filters [22] have widespread use. Some researchers have also created their own autopilots when others [23], [24] have opted along the years on using commercial autopilots, customizing them for their needs.

The visual guidance system implemented in this project is based on a cascade controller that allows the control in the position and orientation of the robot [25], [26].

## III. SYSTEM OVERVIEW

In this section, the developed system will be introduced. The description will be centered on four main subsections. These will discuss the hardware and software implemented, arguing about the reasons behind these decisions, and the practical and theoretical arguments. Figure 1 summarizes both the hardware and software modules that compose the system. Following sections will describe with more detail these modules.

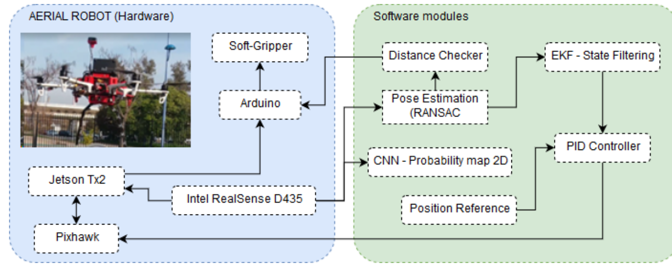


Fig. 1: Diagram of interactions between the hardware and software modules

### A. Aerial platform

The aerial system based on a DJI F550 hexacopter. The reasons for that choice are several. First, hexacopters are more reliable systems, i.e. if one motor has a failure the UAV will still be able to control itself and perform a secure land. This fact is crucial when flying in places where a drone crash could have significant personal and material damages, as for example in refineries or oil and gas-related facilities. Moreover, it is a lightweight platform with a compact volume. This is an important fact because the system is thought to maneuver in the refinery, where spaces between pipes are small and a big sized drone would not be able to fly correctly in such place. Being lighter also reduces the risks of damages in case of an accident.

To adapt and embed the different equipment, additive manufacturing was used to print the pieces needed for the system, using PLA thermoplastic. This technology allows to easily create customized models with complex shapes without tedious manufacturing processes.

The platform also includes a Pixhawk autopilot for controlling the UAV. This autopilot offers great benefits as, for example, being open source. As an onboard computer, an NVIDIA Jetson TX2 was selected. Thanks to his small size that allows being embedded in the aerial robot. It also provides a high-resolution barometer and a dual IMU for redundancy.

The principal visual sensor of the system is an Intel RealSense D435. This camera has excellent performance in outdoor environments with great resolution, making it adequate for the project. The camera is positioned under the UAV, in an overhead position so that the vision of the pipe is clear. After the drone is positioned over the pipe, the camera would be the primary system for getting a successful land. The landing is thought to be vertical so that a gimbal is not needed for this approach. The camera is also as much centered as possible to the UAV geometrical center of the robot so that movements of the drone do not get the pipe out of the vision range of the camera.

Other onboard systems are the GPS or the radio receiver. They provide control and security to UAVs outdoors flights. The UAV will be described in the next section, weighs approximately 3 Kg.

### B. Soft gripper landing system

This section presents the soft gripper developed by the authors. Contrary to rigid mechanical systems, soft materials

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offer beneficial properties for the landing system. The principal advantages of this actuator are: 1) the capability of adapting to pipes of any diameter, and 2) the capability of absorbing the impact on the pipe while landing, preventing the system to dump.

Fig. 2: From left to right bottom: CAD design of the soft gripper landing system; CAD design middle cut;Complete land gear support; Complete aerial platform.

Figure 2 shows the design of the gripper in CAD and the final realization embedded in the aerial platform. The gripper is constructed with three different materials. The core attachment structure, which is used to join the gripper with the UAV, is 3D printed in PLA. This rigid thermoplastic structure adds stiffness to the landing system. It holds the electronic and mechanical parts of the whole system, also maintaining the shape of the gripper. Each of the pair of limbs is created with a flexible material called FilaFlex. It is a rubber-like material that provides the gripper with the rigidity enough for keeping the shape and exerting forces, but flexible enough to bend and adapt to the pipe's shape. Another benefit of using this material is that it can be molded by a 3D printer, which allows creating custom shapes. Finally, the downside face of the limb and the base of the core structure is coated with silicone to increase the grip force and get full soft contact with the pipe. Figure 3 shows the assembly of all the CAD parts.

Some of the gripper's properties are the facts that it is an intrinsically compliant system, allowing a softer landing. It also can adapt to different pipe sizes thanks to the fact that it constricts the drone on the pipe. Furthermore, weight is a crucial variable, in this case, designing the landing system for being 3D printed allows optimizing the weight of it. This is a significant issue in an aerial system, where any additional gram of payload means less flight autonomy and also affects the maneuverability of the UAV. By last, it also offers more security in case of crashes thanks to his softness.

As mentioned before, the weight and the dimensions of the landing system are critical, so that they have been optimized as much as possible obtaining a weight of 304.6 g without the servomotor and 345.8 g with the servomotor, having a dimension of 140 mm width and 96.5 mm height. The limbs or tentacles weight is 36.9 grams each, and they have dimensions of 52 mm width and 230 mm height.

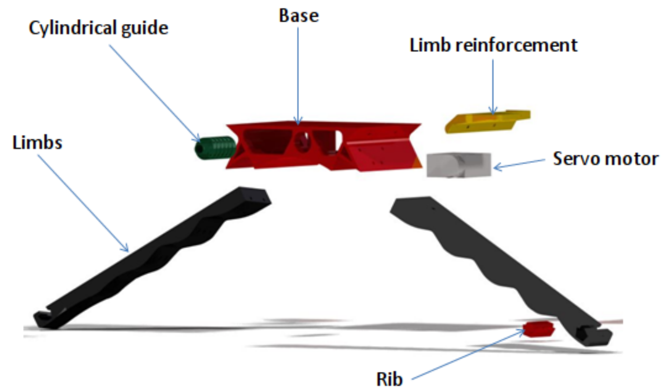


Fig. 3: Overview of the complete landing system. The two limbs can be seen, also the servomotor that applies the force to them. One rib is placed at the tip of each limb to distribute the forces and to reinforce the structure. The base is where all the components are attached. It is modular and easy to change thanks to the dovetail guides

The choice of the limb's shape has been obtained after looking for different nonlinear studies and tests, to observe the limb's deformation and finding the best adaptive shape for the pipe. In the studies carried out, the properties of the FilaFlex material were analyzed. For those tests, the base of the limb was embedded, and a force was applied at the other end. This force was equal to the maximum force the threads would accomplish.

To obtain a good grip and have the highest possible grip range, the stiffness of the joint had to be taken into account. The stiffness formula is $k = EI/L$, where E is Youngs modulus, $I$ is the cross-sectional moment of inertia, and L is the flexible segment length [27].

The first tests were made with $k1 = k2 = k3 = k4$ being $k1$ the joint closer to the UAV and $k4$ the one further away of it. With this setup, the limb started to bend first on the tip, not adapting properly to the pipe. After this first attempt, the length $L$ was varied, making it higher in the joints closer to the UAV and reducing it progressively in the final joints. As a result of the previous entry, $k1 < k2 < k3 < k4$. With this approach, a good adaptation was obtained, getting a smoother landing without collisions with the pipe. Figure 4 shows both designs of soft tentacles.

Equation 1 describes the recursive formula for joint's stiffness.

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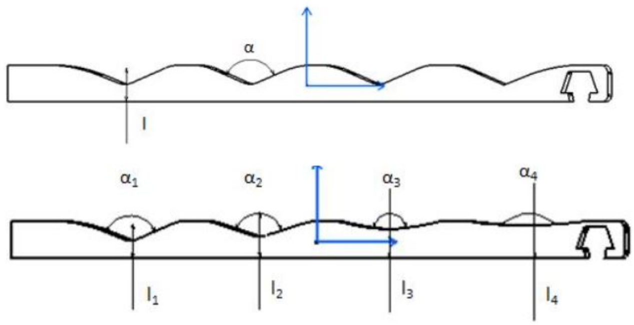


Fig. 4: The top image represents the symmetrical profile with the same angle and the same distance from the base. The bottom image has different angles and the distance to the base also changes

$$
\begin{aligned}
k_n &= \frac{1}{\theta_n}(F_t(m_n g(l_{cn}\cos\sum_{n=1}^{N}\theta_n - \frac{h}{2}\sin\sum_{n=1}^{N}\theta_n) \\
&\qquad + l_{\alpha n}\sin(\frac{\theta_n}{2}) + h)) \\
R_{xn} &= F_t - m_n g \sin\sum_{n=1}^{N}\theta_n \\
R_{yn} &= F_t\frac{\theta_n}{2} - m_n g\cos\sum_{n=1}^{N}\theta_n
\end{aligned} \tag{1}
$$

These equations have been used to determine the joint deflections required to grip a circular cross-section of a particular radius R formed with $\theta_i = \alpha$ angles. This design radius is considered the canonical. Nevertheless, due to the softness of the system, the gripper can envelop pipes of larger and smaller radius. Equations 2 can be used to solve $\theta_i$, giving as a result Equation 3

$$
\begin{cases}
cos(\alpha) = \frac{R+H}{R+H+b} \\
tan(\alpha) = \frac{\alpha+L_{i-1}/2}{R+H} \\
cos(\theta_i) = \frac{L_i}{2a} \\
tan(\theta_i) = \frac{2b}{L_i}
\end{cases} \tag{2}
$$

$$
\theta_i = \tan^{-1}(\frac{2(L_i^2 + L_{i-1} + L_i)(R+H)}{L_i(4(R+H)^2 - L_i^2)}) \tag{3}
$$

| angle | $\alpha$ | $\alpha_1$ | $\alpha_2$ | $\alpha_3$ | $\alpha_4$ |
|---|---|---|---|---|---|
| degrees | 132 | 132 | 135 | 166 | 170 |
| length | l | l_{1} | l_{2} | l_{3} | l_{4} |
| millimeters | 13 | 13 | 15 | 90 | 180 |

TABLE I: different dimensions of limb shape profiles

The conclusion reached was that, in order for the limb to fit as best as possible to the pipe, the shape of the limb should be a progressive deformation from the base of the limb to the end of it. Therefore, as observed in the Figure 5, at the base of the limb the curvature is wider and softens when reaching the end.

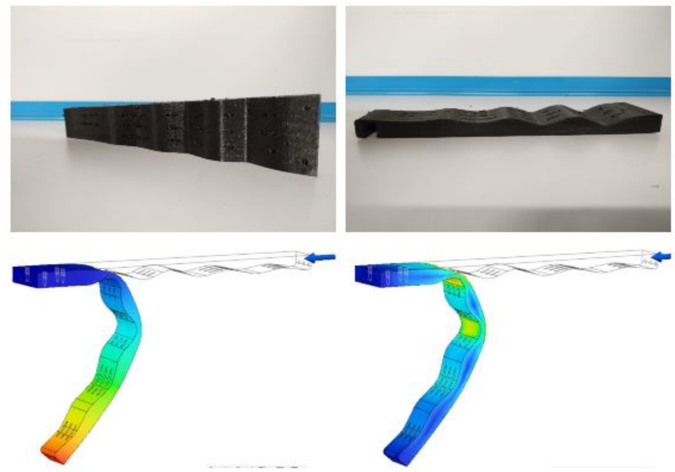

Fig. 5: The top left picture shows the limb printed; The top right picture represents the real profile; The bottom left picture is the displacement study; The bottom right picture shows the stress study

The landing system has been designed to be modular, which has various advantages. In case of failures, it is possible to replace the gripper with another one quickly. Or, for example, to be able to change the shape of the limb during the within flight tests. This was applied using dovetail guides on the base of the landing system. The result is a high advantage in case of operation on pipes of different sizes. With this feature, tests could also be done quicker and several landing gear modifications could be tried out in less time.

The gripper is actuated using nylon threads that pass longitudinally over both tentacles. At the tip of the tentacles, a rib out of PLA has been placed to tie the threads and to add rigidity and distribute the forces. The other ends of the threads are spooled around a cylinder which is also 3D printed. This cylinder is actuated by a small servo motor inserted in the structure. A reinforcement out of PLA is located in the base of the limb to encourage the correct movement. The base of the landing system mentioned above is designed to contain the servo motors of each limb in different compartments.

The presented system is able to adapt to different pipe diameters and materials. It performs enough force to stick the drone on the pipe, stabilizing it and allowing the UAS to turn off the motors. In case that the landing is not successful, any impact of the pipe on the landing system will not harm the system or the object thanks to its flexibility. If during the perching there are small drifts in the position of the UAV, the gripper will also center the drone on the pipe.

### C. Pipe detection

The detection algorithm uses the color and depth images obtained from the Intel RealSense D435 device. The detection occurs in two stages. At first instance, a convolutional neural network uses the color image to perform the segmentation. Then, the segmentation is used with the depth image to estimate the pose of the target pipe accurately.

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| | UNet | SkipNet | Dilation |
|---|---|---|---|
| Pixel accuracy | 90.21% | 92.33% | 95.76% |
| Speed (s) | 0.0601 | 0.0611 | 0.0607 |

TABLE II: Brief comparison between three different CNN frontends.

As aforementioned, a convolutional neural network is used. This CNN is based on the work presented in [28]. The idea behind it is the fact that grouped convolutions and shuffled channels reduce computational cost while maintaining good accuracy.

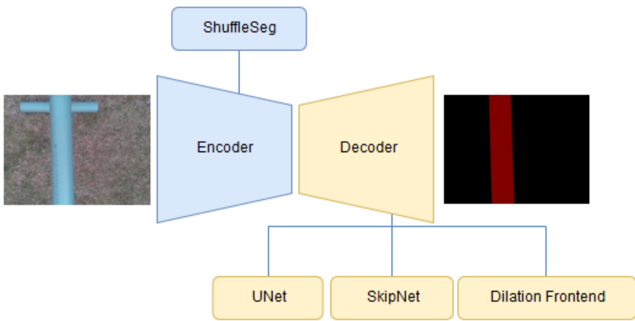


Fig. 6: Graph showing the Encoder/Decoder structure of the neural network used in this paper.

As seen in Figure 6, the network has an Encoder-Decoder structure that is fed with the color images and outputs a segmented image with the same size. There exist several Encoders such as VGG16, ResNet18, and MobileNet. However, the primary limitation in this application is the speed. For this reason, the Shuffleseg encoder structure presented in [14] has chosen.

For the decoder structure, three options have been tested: UNet [29], SkipNet [30] and Dilation Frontend [31]. The selection of this network fragment compromises the trade-off between the accuracy and the speed of the system. Table II shows a brief comparison between the three front ends. All of them take approximately the same computational time, but the Dilatation Frontend overtakes the other options in terms of accuracy. Additionally, UNet and SkipNet tend to create more scatter results than Dilatation.

The result of the network is a mask image, of the same size of the input image, with the segmentation of the different classes. This mask corresponds to the argmax function of the probability of the classes. In the case of this paper, only two classes are searched. The pipe and the background, which will be all the other parts of the image and will be shown as black at the output image.

The argmax image given by the CNN is used together with the depth information provided by the depth camera to create a small point cloud with the points that are candidates to belong to the pipe. However, this cloud is susceptible of containing noise points associated to the noise of the depth camera. For this reason, RANSAC [32] is used to detect the cylinder. This last stage gives a robust estimation of the position and orientation of the pipe which is used for the control system.

Figure 7 shows the results of the pipe detection algorithm. The top image shows the input frames from the Intel RealSense device (RGB and depth images). Bottom left figure shows the argmax image (per pixel class with higher probability) resulting from the CNN. The bottom right figure shows the final results overlaid with the deprojected point cloud from depth. The red points correspond to the inliers of the RANSAC algorithm. Notice, that the computation of the complete point cloud is not needed. Instead, the argmax mask obtained from the previous step is used to estimate the 3D point cloud of the most probable points. The bottom right image of Figure 7 shows in red the points corresponding to the estimation. The complete point cloud has been computed in this case for demonstration purposes.

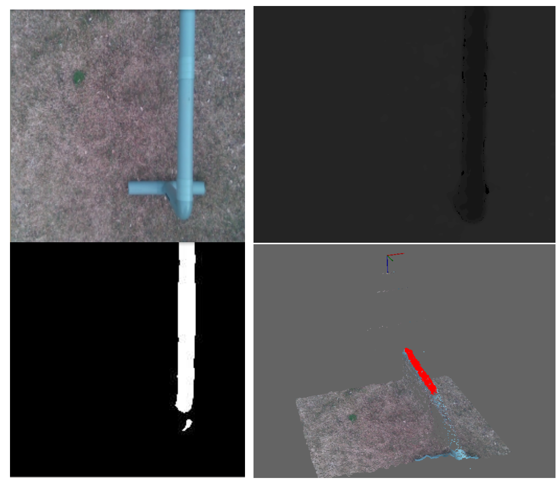

Fig. 7: Top images show the input frames from the Intel RealSense device. Bottom figures show respectively the argmax result from the CNN and the detection from the RANSAC algorithm, which highlight the result in red.

Using the Intel RealSense D435 as camera, the neural network works at a speed of 16 FPS on the Jetson TX2. It has been trained with approximately 2000 images of datasets obtained in manual flights in the same set up as the one used for the validation tests. The images have been labeled manually using an annotation tool and it has been enlarged using data augmentation (shifting, zooming and rotating images). The neural network avoids false positives in this environment thanks to training with a variety of images at different distances and orientations to the pipe. The detection has a high percentage of success which allows keeping the UAV on the pipe.

### D. Visual guidance

To control the UAV a cascade control on the system has been implemented. This approach has been already studied for years in aerial systems [33]. The reason behind the use of it is that it allows using a simple PID algorithm for controlling complex systems like a multirotor. One advantage of using this control system is that it can adapt to changes in the hardware configuration. Usually, such vehicles with non-linear dynamics have a control design based on mathematical models strongly

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related to the physics of the system. The cascade approach allows controlling the system without having to design a model for any specific configuration and adapting to the one used.

For filtering of the control signal, an extended Kalman Filter was used. This method has extensively been used for aerial systems [34]. It allows the system to adapt to the loss of position information so that the system can be stabilized even if the frequency of external data decrease [35] or if some false positives, which could destabilize the system, appear. It also has been proved that it is faster than other non-linear filters, like particles filters, maintaining their accuracy [36]. It is a very extended filter for object tracking [37] so it meets the demands, exposed in this work, of using it for the pipes detection.

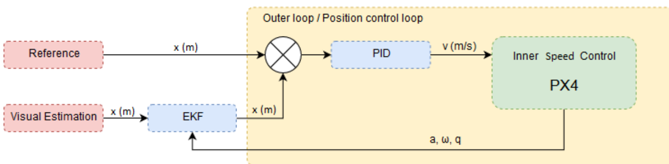


Fig. 8: Graph of the control loop used in this paper. EKF and PID are combined for feeding the PX4 autopilot with information for controlling the UAV.

As it can be seen in Figure 8 the control loop is fed with the UAS reference and the visual estimation obtained by the neural network filtered by the EKF. After that, the PID delivers to the autopilot the desired speed commands to control the position of the robot. The orientation of the robot is also controlled using the visual estimation. Together with the position of the drone, the direction of the pipe is computed too and used as a reference angle to rotate the robot.

During a landing operation, the UAV has two stages. At first, using the controller described before, the UAV centers the pipe in the field of view of the camera while keeping the altitude. Then, one the UAV is centered, it starts a downward motion until it gets close enough to the pipe. Then it activates the soft gripper to attach the UAV to the pipe. Once the gripper is closed, the rotors are turned off.

## IV. Experimental validation

This section shows the experiments carried out to validate the performance of the system presented in this paper. Several experiments will be presented, and the results will be explained. The purpose of the system is to inspect pipes in industrial environments. Thus, a mockup structure has been built with an ”n”-shaped structure with 15 inches PVC tubes. All the experiments have been performed outdoors in a clear area. The system has been tested against different light and climatic conditions. The idea behind this set-up is to simulate a real attachment in some industrial facility with real-life outdoor conditions.

At first, to grant the safety of the aerial platform, a set of static grasps and manual flights were conducted. In these flights, the purpose was to check the gripping capabilities of the soft gripper, particularly, how much the UAV can be angled when landing. After, conducting several experiments, it was determined that the maximum resisted angle by the gripper is $30^\circ$ for PVC tubes. If the UAV exceeds this angle while perching it would slip.

Additionally, one conclusion was that the gripper could effectively hug the pipe even if the platform drifts during the perching. It happens due to the gripping effect of the silicone of the gripper. Figure 9 shows a sequence of an experiment in which the platform drifted approx. 15 cm due to the wind in the last instant before landing. Despite this drift, the gripper pushed the platform towards the right position.

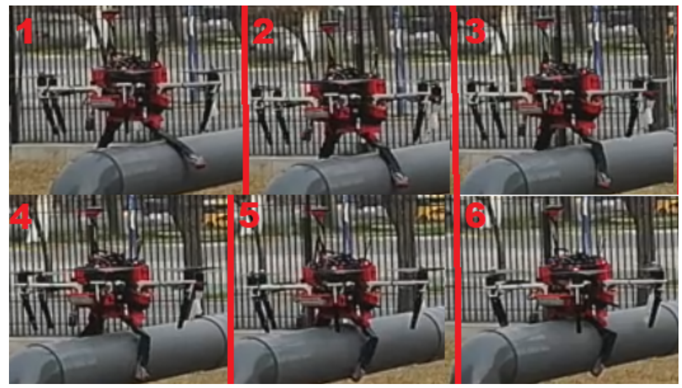


Fig. 9: Position estimation of the aerial platform related to pipe CS. This estimation is the result of the presented vision system and is used to perform the visual control of the robot.

As introduced in Section III, the robot is equipped with a Jetson TX2, which executes the visual detection and control algorithm. The purpose of using this computer is to enable the use of deep learning techniques which are not feasible with conventional onboard computers such as Intel NUC, RaspberryPi, BeagleBone or Odroid. With this set-up, the control signal is delivered at 16 Hz, including the acquisition of the data from the RealSense device, the execution of the convolutional network, the pose estimation and the control system.

Figure 10 shows the results of the vision system during real outdoor experiments. Solid lines show the position of the UAV to the estimation of the pose of the structure. The Dashed lines show the reference. At first instance, the UAV remains in altitude until the estimation converges. Then a ramp in $Z$ is introduced, descending towards the pipe.

Figure 11 shows the resulting reference speed that feeds the autopilot to control it. It can be observed that the speed commands coincide with the errors between the estimated position of the pipe and the reference position. In the beginning, the pipe is in a positive distance so the command speed tries to reduce this error. When the reference altitude starts decreasing the speed command in Z changes accordingly.

The system starts from a static position on the ground. The take-off maneuvers are performed autonomously, sending the UAV to a predefined waypoint over the pipe. After that, the autonomous landing program gets into action and performs the landing operation. When the distance to the pipe is short enough, the soft landing system closes over the pipe. Even if the UAV is not perfectly aligned with the pipe during the perching, the soft gripper pushes the drone, centering it and

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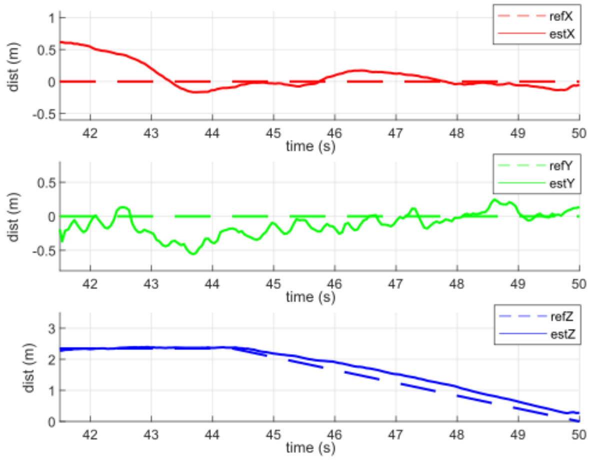


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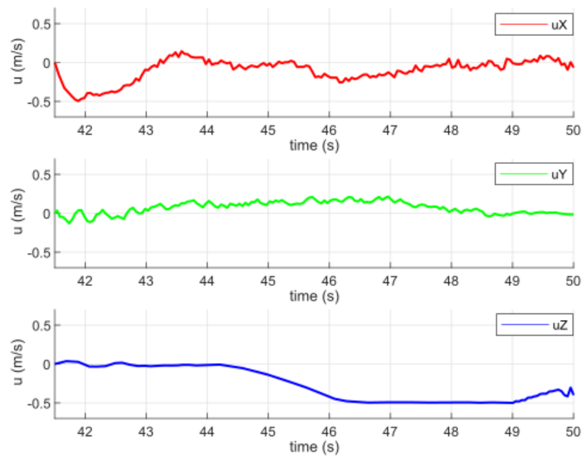


Fig. 11: Resulting control signals from the controller to the autopilot

getting it attached to the pipe. This makes the system perfect to use in windy conditions when the control is not able to ensure a perfect positioning over the pipe.

## V. Conclusion

This paper proposes an aerial system capable of perching on pipes outdoors. This trait is vital since indoor tests do not deal with real outdoor conditions, such as changes in light or wind conditions. As the idea of this system is to work on pipes located in industrial facilities, carrying out outdoor tests is crucial to evaluate the performance against these environmental effects.

Furthermore, landing on pipes involves more risks than landing on typical flat platforms. Achieving this task proves further the reliability of the system. Additionally, PVC tubes have a sliding surface, which makes it more challenging. If the soft gripper is capable of remaining attached to PVC surfaces, it will do in rougher ones. Moreover, the presented system is capable of landing without any magnetic assistance, contrary to other systems that rely on a final help using magnets. Finally, the stability of the platform once attached do not depend on the thrust of the motors, so these can be turned off to save battery while performing any kind of inspection task over the pipe.

It is worth to mention, that this paper focuses on the complete development of the system, from the hardware design to the visual detection and the control design. The design of the gripper combines the use of a servomotor with soft-robotic techniques. The combination of additive manufacturing methods and silicone-based materials offered a good solution to deal between the need for a customized design and the simplicity of working with silicone molds. Additionally, fusing soft-robotic techniques with UAVs is a promising line of research, that will produce safer and more reliable aerial robots.

Future work should be guided to improve the soft gripper. Making it capable of moving over the pipe might be a more energy-efficient solution, avoiding the need to perform takeoff and landing maneuvers. Moreover, adding more softness to the rest of the UAV would be a great line of research, making the UAV safer. For example, isolating the rotors would change the paradigm of industrial aerial systems.

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