Annals of DAAAM for 2010 & Proceedings of the 21st International DAAAM Symposium, Volume 21, No. 1, ISSN 1726-9679
ISBN 978-3-901509-73-5, Editor B. Katalinic, Published by DAAAM International, Vienna, Austria, EU, 2010
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Annals of DAAAM International

DEVELOPMENT OF A LIGHTWEIGHT UNMANNED AERIAL VEHICLE FOR RESCUE AND MAINTENANCE TASKS

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Abstract: *This contribution presents the development of an unmanned-aerial-vehicle in a special lightweight design and is able to drop different cargo with onboard-camera support. The new design allows a payload which is in the field of its dead weight. As a new approach an additional actuator was added to open and close a dropping mechanism while the UAV stays horizontal. A control architecture based on ultrasonic distance sensors and a CMOS-camera is proposed. The performance of the system was proved by several flight tests. Potential applications of the system can be physical tasks at high places like carring load to difficult accessible places as well as rescue or maintenance tasks.*

Key words: *lightweight, quadrocopter, payload, maintenance and rescue task*

1. INTRODUCTION

Carring different items effectively to high or difficult accessable places generally needs significant effort from humans, as they require time and space consuming support systems such as ladders or transportation systems. The risk of injuries to humans by falls is also increased. Therefore working in elevated places is often dangerous and not economically sensible. The development of remote controlled or autonomous systems with the ability to support humans could solve these problems. Thus no additional support from ladders or platforms would be needed and humans would not be endangered. High versatility would also be an advantage of such a system.

Unmanned Aerial Vehicles (UAVs) are remote controlled, semi-autonomous or fully autonomous flying objects. The size, level of autonomy and the kind of thrust generation can greatly vary between different types of UAVs. These aircrafts are most often used for surveillance and reconnaissance, aerial photography, exploring areas, which are dangerous or difficult to access during rescue missions and also for research purposes.

UAVs are a promising type of robot which can be applied to a large variety of tasks. The development of a UAV with a lightweight design for carrying different equipment like tools, safety equipment, e.g. to difficult accesable places opens a great spectrum of new application possibilities for this highly versatile technology. This paper presents such a development. The UAV was modified using high-tech materials and reduced to it's main functional components.

2. RELATED WORKS

Besides traditional types of robots, like rail- or cable guided (Elkmann, et al., 2008), there are different types of autonomous robots suitable for tasks in high places which are listed below:

Climbing Robots are special robots for the work at steel structures, such as bridges or gas and oil tanks. Usually these robots are able to climb by using magnetic forces (Fischer et al., 2007) or vacuum (Zhang et al, 2006). The climbing robot presented in (Chen et al., 2008) also uses an aerodynamic principle, the Bernoulli-effect, to create an attraction force. Other approaches use electro adhesion (Prahlad et al., 2008), which can create adhesion forces on a variety of substrates.

Flying Robots are mainly used for reconnaissance and data collection tasks, surveillance and applications in dangerous areas. Often the robots are able to take off and land autonomously and vertically (VTOL). Examples of UAVs can be found in (Remuss et al., 2002 and Scherer et al., 2007).

Flight-type Wall-Climbing Robots are the combination of climbing and flying robots and built by Prof. Nishi of the University of Miyazaki, Japan. He developed propeller driven climbing robots which are capable of flying over obstacles in order to reach a wall and then climb up this wall (Nishi & Miyagi, 1994).

3. CONCEPT

3.1 Dead weight reduction

One of the main aspects to increase the efficiency of any UAV is reducing its mass. The lighter the quadrocopter the longer the maximum flight time and the bigger the payload. The structure of such a platform can be very simple which is the main advantage of multicopters. That means apart from the electronic components only few parts remain which can be optimised. One of these parts is the beam where each engine is mounted. They must have a certain length and the applied maximum force is very well defined due to the maximum thrust of each engine and propeller, if not taking inappropriate handling into account. Stress related design is the key factor for efficient engineering which means designing the beam according to its bending stress. In order to select the right material these two formulas are most important:

Both M_1 and M_2 should be as high as possible to have a material both stiff and strong. Material selection diagrams help compare the different materials for option (Ashby, M. F., 2007). In this case extruded carbon fibre reinforced plastics is a great option.

For lightweight design the form factor is one of the most relevant figures in order to define the shape of the beam. As bending stresses are highest at the top and the bottom of the beam, any hollow structure will perform better than solid structures with the same weight. The form factor is the figure that takes this into account. The beam chosen for this prototype is an extruded carbonfibre reinforced plastic rod of square shape. The young modulus for bending is 110 GPa with a strength of 1700 MPa, having a density of only 1.65 g/cm^3. The wall thickness is only 0.5 mm with the dimension of 8 mm. The form factor for bending stiffness is around seven which means it is seven times more efficient than a solid beam of the same mass. The safety factor is still around 60, giving enough resistance towards inappropriate handling (e.g. crash). The form factor can be improved by increasing the dimensions and making the walls thinner. This, however, results in a rod that can easily snap with minor dents. Furthermore, the beam is directly below the propeller and would affect the air flow significantly. As the manufacturing of thin-walled rods is very complicated and not very reliable, adapting pieces have been glued into the rod in order to avoid having to drill into it. The adapting pieces are made of a glassfibre reinforced polyamide. The amount of short-fibers is 30 %, allowing reliable lathing, milling and drilling with the advantage of a relatively high stiffness and strength.

Like the beams for the engines, all other parts have been designed in a similar way. A multi purpose plate for mounting further equipment has been attached by using round, hollow carbon rods with glued in threaded rods. The threaded rods as well as most other screws are made of glassfibre reinforced polyamide. M3 screws have a tensile strength (~ 600 N) which is enough to withstand all occuring forces but still serves as a predetermined breaking point in case of crashes during testing.

A good material for designing difficult shapes at low costs is watercut carbonfibre reinforced plastics with a thermoplastic matrix. Wood forms can be milled to serve as bending mould. In order to bend the carbon parts, they have to be heated to 170°C and can be pressed around the wooden form.

In Figure 1, the complete view of the quadrocopter with a first aid kit attached can be seen.

Fig. 1. Complete view of the quadrocopter

3.2 Camera support

A small wireless camera with an angular field of view of 160° (f=1.8 mm) is attached to the quadrocopter. The power supply is realized by a power converter which uses the main battery to reduce additional load by a second battery. The camera weight is 16 g, has a range of 100 m and an output frequency of 2.4 GHz. It is attached to the quadrocopter using carbon fiber reinforced plastic plates. It supports the users for a precise dropping of items.

3.3 Dropping of items

To drop items off automatically a multipurpose release mechanism was designed. The actuator is a lightweight servo-motor with a torque of 10 Ncm, using a carbon transmission. The motor pulls a string which is attached to a pin. A spring ensures that the pin remains safely in position without the actuator applying any force, thereby saving energy. The pin is guided by a plastic bush bearing. In order to avoid friction and wear, the pin itself is made of aluminium. Fiber reinforced materials can cause quick wear on bearings without reinforcement. All bearing housings are made of glassfibre reinforced polyamide.

4. PHYSICAL PLATFORM

In order to stabilise the platform, two types of sensors are mounted onto the control-board. Gyroscopic sensors are installed to detect rotations (three axes), and one additional acceleration sensor. Once calibrated, the acceleration sensor can detect the exact direction of the gravity in order to hover stable without drifting too fast in one direction. The gyroscopic sensors support the stabilisation of the platform. A barometer can detect the air pressure and control the height of the UAV.

The battery type used for this platform is a Lithium-ion polymer battery. These battery types ensure a high energy density per mass. The capacity used is 2.2 Ah which results in a hovering flight time of 20 min. without additional payload.

5. CONCLUSION

Due to the lightweight design, the total weight could be reduced to 690 g which lead to an increase in flight time of 43 %. To increase the flight time it is always possible to increase the capacity of the battery, but the payload will decrease and the power consumption will be higher due to the additional mass. This platform is optimised for either 20 minutes flight time without additional payload or a flight time of 10 minutes carrying 400-500 g. As it is intended to drop the cargo, the total flight time is around 15 min. to complete the task. Possible scenarios are maintenance and rescue tasks. Especially natural desasters like flood is a great fiel of application, because it can be used to drop first aid items, medicine, communication equipment, e.g. in a flexible way. Using multiple UAVs makes a disaster relief operation very effective and the chance of survival increases.

To access future markets, additional research has to be done. Especially an intuitional human – machine interface has to be developed which allows the use of the UAV without special learning and regular training.

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