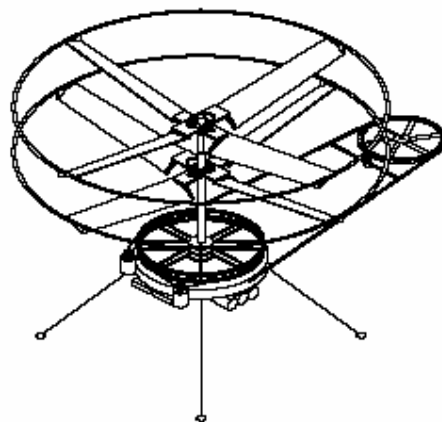


Passively stable Micro VTOL UAV

by

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Summary

Normally VTOL and hovering UAVs are considered to be unstable and difficult to control unless they are equipped with sophisticated sensors and electronics.

The Proxflyer co-axial rotor helicopters utilize a new mechanical and aerodynamically approach to the challenge of achieving stability. This patented concept has been developed over many years by the company Proxflyer AS in Norway and the most unique feature offered by these small VTOL and hovering aircrafts is that they are passively stable. They are stable with respect to the surrounding air and are therefore ideal for indoor use.

So far the concept has been used with success in small UAVs and aircrafts equipped with wireless video cameras, low cost fully functioning toy helicopters and in sub-micro helicopters like the Micron and the Nanoflyer.

Background

Petter Muren, the owner of the company Proxflyer AS has 30 years experience in designing and building remote controlled airplanes and helicopters. 15 years ago the development of different electric powered helicopters started. These, mostly tandem and co-axial type helicopters, were large models and they were far from being passively stable. Several of them never made it into the air. The battery technology at that time did not allow for long flights, hence most of the early models got electric power via a tether from the ground.

The work on the Proxflyer helicopters as we see them today, started about 5 years ago. These early concepts challenged the “known” facts about the stability of helicopters and they were based on the previous co-axial rotor models. It has always been a target to have as stable helicopters as possible, but at the same time they needed to handle wind, turbulence and have as high forward speed as possible. Because of this there has not been considered practical to try to stabilize a helicopter solely with respect to the surrounding air.

Battery technology and constantly smaller control electronics have finally made micro indoor flying platforms a real possibility. The main difference between indoor and outdoor environment is the lack of wind and turbulence.

Maybe the “impossible” passively stable helicopter could be realized by approaching the stability problem in a completely different way. What if it was possible to achieve hovering flight that was completely stable with respect to the surrounding air? Would it be possible to design a helicopter that

interacted with the air in which it was flying in such a way that it passively remained fixed at one position in space?

The concept

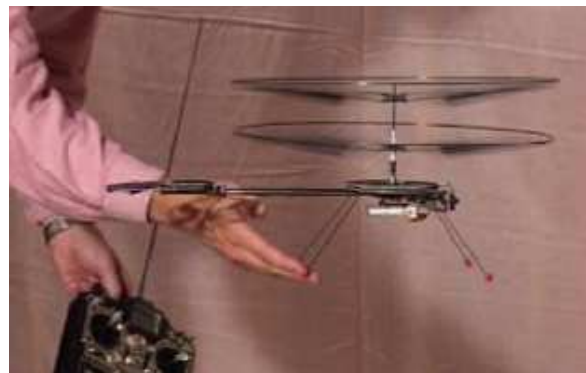
The main benefits are:

- Passively stable
- Simple electronics, no servos or actuators
- Relative simple mechanics
- High efficiency, long flight times
- Very easy to pilot
- Very low noise level

Possible disadvantages are:

- Relative low forward speed
- Not possible to operate in wind (outdoors)

The rotors used in these passively stable aircrafts have a generally fixed geometry and they are tiltably connected to their rotor shafts. However, the inner part of the rotor blades have a pitch angle that is fixed relative to a reference plane perpendicular to the rotor shaft, whereas the outer part of the rotor blades have a pitch angle that is fixed relative to the rotational plane of the rotor. The fixed pitch in the outer part comes from the tip of the rotor blades being fixed to a ring. This ring by definition lies in the rotational plane of the rotor.



The Proxflyer Mosquito uses this new rotor concept.

The fixed pitch angle in the inner part of the blades together with the blades being connected to the ring would seem to imply a rigid rotor. However, because the very thin and curved rotor blades can twist along their center line, the rotors are in fact more or less free floating with respect to the helicopter. The rotor can easily tilt in any direction. If the rotating plane is tilted, each rotor blade will go through a cycle of tilting (move up and down) and twisting as the rotor spins. Together with the co-axial design, the free floating rotors eliminate unwanted gyroscopic forces between the rotors and the helicopter.

At the same time, due mainly to aerodynamic forces, the rotors will follow any tilting of the rotor shaft, thus allowing the helicopter to be maneuvered by just gently tilting it in the desired direction of flight. This is achieved because the inner part of the rotor blades have a fixed pitch angle with respect to the reference plane perpendicular to the shaft. If the rotor has been tilted and the blades follow a tilted path with respect to the reference plane, the rotor blades will move up and down as they rotate and the inner part of the blades will actually have different angles of attack in different parts of the rotation. This again, gives different lift in the different parts of the rotation, tilting the rotor back to be perpendicular to the shaft, or in other words; stabilizing the rotors with respect to the rotor shaft. This also secures that the rotors follow any tilting of the helicopter.

Because the outer part of the rotor blades have a pitch angle fixed relative to the rotational plane (the ring), the rotors have a high tendency to back-flap or tilt up in front due to horizontal movements. This high tilting tendency is the opposite of normal desired rotor behavior and ensures that even small movements with respect to the surrounding air, will tilt the rotors and try to stop or slow down the horizontal movement of the helicopter. This is also more or less the opposite action of what the inner part of the rotor blades does, and these two functions may be tuned against each other to achieve more or less stability.

The concept in its current configuration allows for moderate forward speeds and operations under no-wind conditions and it provides absolutely stable hover without use of any electronic control systems.

The rotors operate at very low RPM and together with the co-axial design and up to 8 rotor blades the efficiency of this helicopter is very good. With the latest in battery technology the 120 grams Mosquito could easily fly for almost 1 hour. The low RPM together with the gear system using rubber bands and pulleys enables absolutely silent operation.

The control is very easy:

- Vertically the helicopter is controlled by the speed of the two main rotors.
- Yaw control, turning the helicopter from side to side, is achieved by increasing the speed of one rotor and reducing the speed of the other rotor by the same amount.
- Horizontally the helicopter is only controlled in forward and aft direction. To enter into forward flight the helicopter is tilted by a small horizontally orientated propeller positioned at the back of the helicopter. The main rotors follow the tilting of the rotor shaft and pull the helicopter forward.
- To go sideways you first have to turn the helicopter in the direction you want to go and then fly forward in that direction.

The control of this helicopter is not very different from what you do when you control a RC car with the only addition being vertical motion. If for some reason you loose control, you simply let go of the control stick and the helicopter will enter into stable hover by itself.

Stable platform for wireless camera

The 120 grams VTOL Micro UAV Mosquito utilizing this co-axial rotor principle has been used in several appearances and demonstrations. With its onboard 2.4 GHz wireless video camera it has been used to i.e. filming an audience while flying overhead inside a conference room. The pictures can be recorded or displayed on monitors.



The Proxflyer Mosquito equipped with a wireless video camera is controlled solely by looking at a large video conferencing screen displaying the pictures coming from the helicopter.

In August 2003 this helicopter performed what is believed to be the first ever controlled flight where the pilot operated the helicopter solely by looking at a large video conferencing screen displaying the pictures from the helicopter. The pictures were transmitted to the remote location by a Tandberg video conferencing system. The stable helicopter performed two successful flights of approximately 1 minute. Each flight included: Take off, forward flights, turns and a controlled landing. During one of the flights, the pilot at the remote end, purely by observing the pictures coming from the helicopter were able to discover and recognize a person coming into the room where the flight took place. The helicopter was controlled by a normal RC transmitter capable of sending control signals to the remotely located helicopter. No gyros or any kind of positioning system were used.

Electronic compass, MEMS gyro and precision pressure sensor

The Mosquito helicopter has an optional electronic compass that may be used to control the heading.

The compass utilizes a 2-axis magnetic sensor from Honeywell. This sensor is connected to the control and mixing micro controller onboard the helicopter and in "compass mode" the yaw input from the remote controller is used to adjust the desired heading with respect to magnetic North. A control routine then adjusts the differential speed of the counter rotating rotors to maintain the desired heading. Experience has, however, shown that the Earth's magnetic field is very easily disturbed inside buildings and therefore the electronic compass is not reliable for indoor use.

For remote operations inside a building it has been demonstrated that keeping the correct height is probably the most difficult task. If the UAV is controlled by the feedback from an onboard camera it will be essential to have additional guidance from sensors giving height information. Preliminary studies indicate that it is possible to have precision pressure sensors with a resolution of less than 100 mm for relative height measurements. One of the challenges using a sensor like this is the pressure differences in the down-wash from the rotors.

In addition to the electronic compass it will be necessary to incorporate a yaw rate sensor or gyro sensor. MEMS gyro sensors from Analog Devices are relatively easy to connect to the onboard micro controller.

Future plans for improving the Mosquito VTOL Micro UAV involve both the use of a pressure height sensor and a MEMS gyro.

Micron and the Nanoflyer

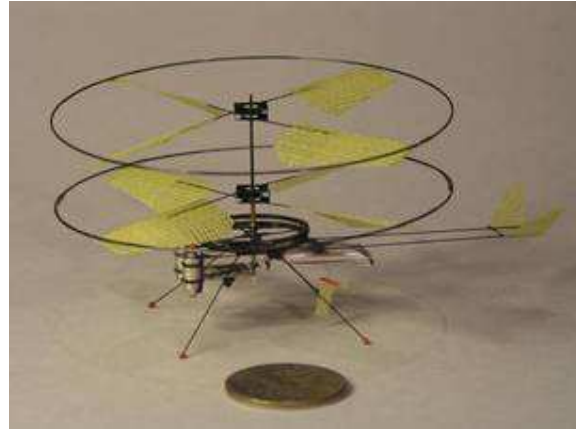
The Proxflyer helicopters have no need for servos or other control systems; hence, it is possible to build very small and light weight sub-micro helicopters or Nanoflyers.



The 6.9 grams Proxflyer Micron from 2003

In December 2003 the 6.9 gram Proxflyer Micron was presented. This was probably one of the smallest and lightest helicopters ever built at that

time. To save weight it utilized only a 2 channel FM receiver, a small 6 mm motor and a 45 mAh lithium polymer battery. With a rotor diameter of 128 mm and equipped with a slightly larger 90 mAh battery the flight time is now around 10 minutes. It has a lifting capacity of 1-2 grams, probably just enough for a micro video camera and a radio link.



The 2.7 grams Nanoflyer from 2004

The latest development is the Nanoflyer; it was presented in September 2004. This is by far the smallest helicopter presented to the public. It has a rotor diameter of 85 mm, two 4 mm electric motors and a 20 mAh lithium polymer battery. It is controlled by a short range 2 channel IR link with onboard mixing and high frequency electronic speed controllers. The Nanoflyer has a flight time of about 1 minute and the total weight is 2.7 grams - less than the weight of a half sheet of paper.

Future UAV development

- Roll control: To further improve the control and the ability to precise maneuvers, a second vertical tail propeller will be introduced. The two small propellers will be arranged so that they are placed on tail booms pointing back and to each side. When operated with similar thrust direction they will give pitch control (as on the present models), but when operated with opposite thrust directions they provide roll control. The controls of this aircraft will now be identical to those of a normal helicopter.
- Outdoor version: The current Proxflyer helicopters are completely stable with respect to the surrounding air. This limits the possibilities for operations under windy conditions. Work is under way to try to maintain some of the inherent passive stability and at the same time reduce the influence of wind and turbulence. It might, however, prove to be very difficult to achieve this without some kind of active control of the rotor blades.

Toy helicopters

Because the helicopter is passively stable it is also extremely easy to control. It is actually so easy to fly that a child without any experience from helicopters or model airplanes is capable of flying it, even the first time they try.

This unique simplicity has led to the development of the BladeRunner toy helicopter. This helicopter is currently produced in China and will be sold world wide. So far more than 80.000 are produced, with estimates to pass 100.000 before Christmas 2004. The toy helicopter has a weight of 50 grams, a rotor diameter of 290 mm and a normal flight time of 5 – 8 minutes.



Bladerunner, 50 grams RC toy helicopter utilizing the Proxflyer rotor concept.

Possible one of the most interesting aspects of this toy helicopter is the low production cost. The reason for this low cost is the very simple concept and design, high production volume and also the fact that it is produced in China. The normal retail price is well below 100\$ US with everything included (helicopter – ready to fly, remote controller and battery charger).

Conclusion

A passively stable Micro VTOL UAV is possible. By utilizing the ideas demonstrated in the different Proxflyer helicopters, it is possible to achieve hovering flight that is completely stable with respect to the surrounding air.

Such a Micro UAV is very easy to operate, it is a stable platform for i.e. wireless cameras and it can be made completely silent. It is ideal for indoor operations and most importantly it can be manufactured at a very low cost.

Links

www.proxflyer.com

www.interactivetoy.com

www.rcgroups.com/forums/showthread.php?t=279923

www.tandberg.net