eMotionSpheres: A New Design for Human-Friendly UAVs

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ABSTRACT

Here we present a new design for human-friendly UAVs (Unmanned Aerial Vehicles). Contrary to conventional UAVs like gyrocopters or quadrocopters, the so called eMotionSpheres feature high process stability, long endurance and furthermore allow for a safe human-machine interaction. Since these features are essential for UAVs used in a production environment the eMotionSpheres will open up new applications of UAVs in the future. Each flying object consists of a helium filled ballonet and is driven by eight small propellers, which are attached to the outer shell. The propellers are a novelty when it comes to flying objects. They consist of a laser-sintered rigid outer frame which is spanned by a thin foil. This design, inspired by the dragonfly wing, results in a light-weight drive, which is adaptive and most interestingly supplies the same efficient thrust in a forward and a reverse direction. One or several of the eMotionSpheres can move in an autonomous or coordinated manner within a defined space. Therefore the flying objects communicate via active markers with a camera system. The cameras reconstruct a 3D space and together with a central master computer specify the flight paths of the spheres. Since the camera system is easy to install and calibrated in few minutes it offers, together with, but also without the spheres, several interesting applications in guidance and monitoring of the networked factory of the future.

1 INTRODUCTION

The civilian use of quadrocopters and other Unmanned Aerial Vehicles (UAVs) grows steadily. Geologists use them to collect data about ancient ruins [1], biologists survey and map forests and biodiversity to protect animals and their natural habitat [2]. Mountain Rescue uses quadrocopter to detect avalanche victims [3] and photographers and videographers provide totally new and impressive sights of sporting events. However, the industrial use of UAVs is still limited. The main reasons for this are the limitation in flight time, the process stability that is costly to achieve and the risk of injuring humans in the case of failure.

Here we present a totally new design for human-friendly UAVs that, combined with an interactive infrared technology, provides high process stability, long endurance and allows for a safe human-machine interaction. Each sphere of the eMotionSpheres has a diameter of 95 cm and is filled with helium. The helium provides buoyancy to lift the spheres even when the battery runs empty.

Eight small propellers are attached to the outer shell of the spheres. They enable the spheres to fly, climb or descend quickly up and down and to move horizontally in any spatial direction to an accuracy of 1 cm. The propellers are inspired by the dragonfly wing and hence are very lightweight and flexible and thus are not dangerous to humans.

Ten infrared cameras installed in the room record the spheres via their active infrared markers. Compared to passive markers, a larger space can therefore be recorded with the same number of cameras. Furthermore the markers are not permanently lit, but instead flash for only 250 µs which make the system highly energy-efficient and allows for long flight-times. The position data is passed on to a main computer. The actions calculated on the main computer are sent back to the objects, where they are locally implemented. On the computer there are preprogrammed paths, which specify the spheres flight paths when flying in formation. Thanks to additionally stored behaviour patterns, the spheres can however also move autonomously through the space. There are no collisions even in chaotic situations as they move out of each others way. As the spheres stop at their charging stations regularly and autonomously, they can be used as flying objects for several days without a person having to intervene.

2 FLYING OBJECTS WITH ADAPTIVE BIO-INSPIRED PROPELLERS

For the eMotionSpheres we combined knowledge obtained from rotorcrafts with knowledge obtained from aerostats. Rotorcrafts as helicopters or quadrocopters are heavier than air and use lift generated by rotor blades while common aerostats are lighter than air. In balloon flight, buoyancy is provided by a carrier gas, e.g. hydrogen, helium, superheated steam or hot air, in an enclosed space. Since hydrogen is highly flammable it is not suitable to be used in a production environment. Steam or hot air are no viable alternatives either for long term use because it loses its buoyancy when cooling down. Helium is not used often since it is too

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Figure 1: eMotionSpheres: an interactive infrared camera system enables both the formation and individual flight of the spheres.

expensive. Here, however, we use a 7-layer bidirectionally stretched PE/PP film with a thickness of only 25 µm and a weight of only 27 g/m^2. This foil is so dense that virtually no air leaks from the spheres allowing to generate a stable system for several days. This way the high price of the helium becomes reasonable.

Each sphere has a diameter of 95 cm. Since 1 m^3 of helium generates approximately 1.1 kg weight of buoyant force the helium can carry a weight of up to 500 g. Thereof the weight of the shell, the onboard electronics with 12 processors, the radio unit, the battery and eight LEDs, four infrared LEDs for communication with the cameras and four power LEDs for light signals, and especially the 8 propellers, have to be subtracted. The helium thus ensures that the spheres swim in a sea of air. This way the propellers do not have to carry the full weight of the spheres but are mainly used for the precise positioning of the spheres in 3D space. This setup results in an energy-efficient overall system since the propellers are only active when needed.

Eight propellers are attached along the equator of the spheres, four of them aligned horizontally. They enable the spheres to fly, climb or descend quickly up and down. Thanks to the four vertical propellers, the spheres can move horizontally in all directions and rotate about their vertical axis. Four of the propellers are screwed anticlockwise and the other four clockwise, with an anticlockwise drive always being located opposite a clockwise one. In this way, the torques are neutralised and the spheres can be steered precisely. The actions from the main computer are sent to the spheres and locally implemented by the activation of the eight brushless motors. The corresponding 8 processors are installed onboard the spheres.

The propellers represent something totally new when it comes to flying objects. For precise positioning of the spheres it was mandatory to have powerful rotors. However, they had to be lightweight at the same time. Therefore we looked at an interesting natural role model: the dragonfly. Dragonflies execute the most complicated flight manoeuvres. Astonishingly, a wing weighs only about 0.002 g although they span a distance of up to 10 cm [4]. Dragonflies can reach a maximum speed of 54 km/h and with some tailwind they can fly up to 1000 km [5]. Some dragonflies even have been observed to fly with half a wing missing. The wings consist of a thin transparent membrane strengthened by a number of longitudinal veins. The membrane has a thickness of 3 µm at its thinnest point [4]. The front edge of the wing consists of much thicker veins with a thickness of up to 220 µm. Thus the membrane is quite flexible compared to the rigid and stable edge. Based on this structure the dragonfly wings show an interesting effect. While flapping up and down the rigid edge leads the movement but the membrane moves like the

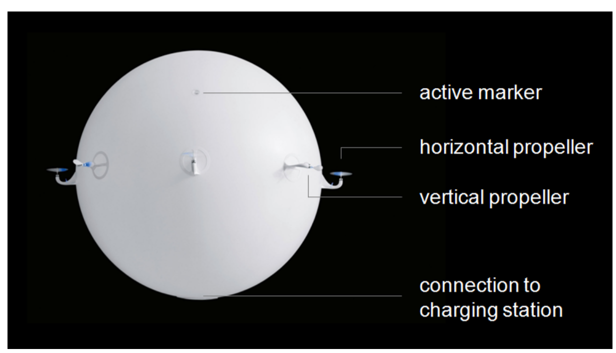

Figure 2: Each sphere has four vertical and four horizontal adaptive propellers. The four active markers are embedded into the shell. At the bottom of the sphere is a connection to the charging station. For charging, the sphere autonomously approaches the charging station then performs a 90° rotation to interlock with the station using a bayonet fitting.

sail of a sailing boat and thus form a profile comparable to the shape of rotor blades [6]. We analyzed the wing deformation of dragonfly wings when we were developing the BionicOpter, a Micro Aerial Vehicle, inspired by the dynamics of dragonfly flight [7]. The knowledge gained from the work on the dragonfly wings went into the design of the adaptive propellers.

Just like the wings of the dragonfly the spheres propellers are made of a sturdy frame covered with a flexible membrane. The frame is twisted once, thus making a figure of eight. The frame is made of laser-sintered polyamide and a few millimetres thick. The membrane consists of translucent PE and is only 5 µm thick. As the film is not under complete tension, it inflates on one side or the other, depending on which direction the propeller is turning. Thus the adaptive propellers have a profile modification based on the direction of rotation. With 7.8 V and 2.2 A they supply 42 g of thrust both forwards and backwards and are thus equally efficient in both directions. In flying objects, this efficient combination of equal thrust performance in two directions is a genuine first. Furthermore, it facilitates to balance the forces across the eight propellers of the spheres leading to the precise positioning performance of the eMotionSpheres. Finally the propeller weights less than 1 g. Due to this lightweight construction the rotation direction can be changed almost without any delay.

The lightweight design of the adaptive propellers has one additional important advantage to standard quadrocopter or gyrocopter propellers: the propellers are flexible and lightweight and thus do not have to be shielded. The new propeller design, together with the buoyancy provided by the helium guarantees safe interaction between the spheres and humans.

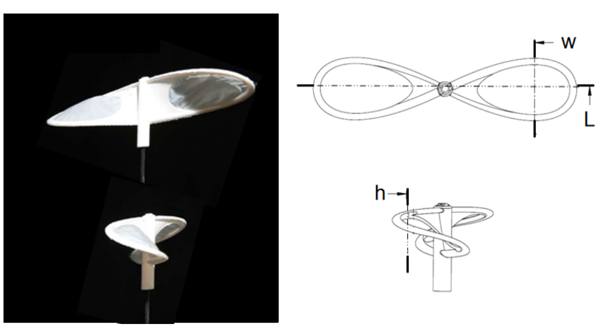

Figure 3: The adaptive propellers have a length of 9 cm, a width of 2.2 cm and a height of 1 cm. They consist of a laser-sintered sturdy frame covered with a flexible membrane, which is not under complete tension. Because of this flexible structure inspired by the dragonfly wing they are not dangerous for humans. Most interestingly the propellers generate identical thrust in both directions.

3 Exact positioning thanks to interactive infrared technology

The drives are adaptive and supply the same efficient thrust in both a forward and reverse direction. Together with the camera system and an intelligent control system, the eMotionSpheres are capable of the widest range of flight manoeuvres with or without a human pilot.

Most state-of-the-art infrared marker-tracking systems measure the displacement of objects by tracking a set of reflective dots mounted to the objects. Infrared cameras installed above the recording area are equipped with an array of infrared LEDs and send out light. This light is then reflected by the passive markers. The cameras then record a picture detecting the reflection. This way the light has to travel the distance from the camera and back. Because of this and because of the dispersion of reflection the size of the recorded space is limited.

For our system we use active markers instead. Four infrared LEDs are embedded in the shell of the spheres on the upper hemisphere of about 45° latitude. Compared to passive markers, a larger space can therefore be recorded with the same number of cameras. With the setup described here a space of more than 30 m to 30 m can easily be covered. The flashing of the active markers is not only used to define the position of the sphere in space but to identify its orientation as well. Furthermore, the pattern of light flashes is used to tell the optically identical flying objects apart.

The exact positioning is based on an interactive infrared technology. This means, that the cameras only take pictures when the active markers are illuminated. POINT GREY infrared cameras are positioned so that they map out the flight area as a whole. Due to special filters, the used cameras only capture infrared light and are not sensitive to other surrounding light. Because of the positioning of the active markers we installed the cameras in such a way that the cameras look down to the spheres from above. Each sphere is recorded by at least two cameras. Since we used 8 spheres for testing 10 cameras were installed. This way occlusions were ruled out efficiently. In order to know where the flying spheres are located in space, the computer first must know the positions of the cameras. Therefore a manually controlled sphere with a measuring cross of defined size flies through the space for 15 min while being recorded by all cameras. The recorded random trajectories are then used to recalculate the exact but relative positions and alignment of the cameras (for more information on multi camera calibration see e.g. [8]). In total the whole calibration process only takes a couple of minutes. Due to the relatively cheap cameras and because of the quick and easy calibration process the system is suitable to be used in a production environment.

Active markers however have one drawback which is the power consumption. To keep the power consumption of the four infrared LEDs to a minimum the markers are not permanently lit, but instead flash for only 250 µs. As a result the

Figure 4: Infrared cameras are used for exact positioning of the spheres.

markers are highly energy efficient. The short illumination times of the active markers makes is necessary to synchronize the cameras with the active markers. A newly designed board on the spheres communicates with a second board mounted to the cameras using radio signals.

In total 12 microprocessors are integrated into each sphere. 8 control the brushless motors of the rotors. The others are used for the interactive communication between the spheres and the cameras and for the communication with the main computer. The main computer defines the trajectories of the spheres while the stabilization of the spheres is calculated on board based on an 10 DOF IMU with integrated gyroscopes and acceleration sensors.

Equipped with a 2200 mAh Li-poly battery the average flight time of a sphere comes to two hours depending on the flight speed and manoeuvres that are flown. As the spheres stop at their charging stations regularly and autonomously, they can be used as flying objects for several days without a person having to intervene.

4 Conclusion

The eMotionSpheres represent a new design for human-friendly UAVs. The spheres are quickly moved in space using 8 adaptive lightweight rotors inspired by the dragonfly wings. The flexible propellers are extremely efficient in both directions and most importantly not dangerous to humans. Helium together with an autonomous charging system allows for flight time of several days. The interactive infrared technology allows to position the spheres precisely in an enlarged 3D space. Because of these reasons the eMotionSpheres open up new applications of UAVs in a production environment.

Generally speaking, the spheres could be conceivably used as a guidance system whether for people working in factories or for visitors at trade fairs, museums or large indoor events. Most interesting is the field of moving sensors [9]. If data has to be obtained from different points within a production line the same sensor has to be installed at all of these points of interest. Some sensors however often must be calibrated or cleaned, or are just expensive. In such a case it makes sense to use one sensor and move it from point to point. In such a case the sensor could be mounted to a sphere which patrols the points of interest on a regular basis, collects the data and returns the sensor for calibration or cleaning. The camera system itself, with or without the spheres, could be used as a monitoring system of a factory. It pinpoints the positions of products in the factory, analyses them and thereby improves the production process. In the field of smart logistics [10] the system could be put to use as a way of monitoring the function of small robots or forklifts. Our system has a clear advantage here because of the enlarged space coverage resulting from the active markers. Finally, the system can also be used to improve human-machine interaction and increase the safety for workers. The system can track movements of workers within a factory and stop machines when the workers get to close to dangerous setups. Taken together the eMotionSpheres together with the interactive infrared camera system describes several new ideas that will open up applications of UAVs also in a production environment.

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APPENDIX A:

A video showing the flight behaviour of the eMotion-Spheres can be found here: http://youtu.be/5iqP1oPZ3Qw