A quadrotor platform for bio-inspired navigation experiments

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I. Introduction

Due to developments driven mostly by the demands of the mobile communication industry and preparatory work by model aircraft flyers, it is possible to construct different sorts of electrically powered flying robots that can carry an interesting amount of payload in sensors and computers.

We are interested in realising autonomous navigation capabilities on real flying robots which should suffice the following requirements:

- self-sufficient in the sense of not relying on external systems of reference such as GPS, visual tracking or similar means
- self-sufficient in the sense of being able to do all necessary computations onboard the flying robot
- usable indoors and outdoors

Specifically we are working with quadrotor helicopters as the experimental platform since they can be built robust and powerful enough for indoor and outdoor flight, besides having other useful characteristics of locomotion (near holonomicity).

Since the problems listed above are not easily soluble in general and conventional methods are easily subject to *brittleness* we expect bio-inspired solutions of parts of those problems to be the most promising path. These solutions pertain to sensory modalities, sensori-motor coupling and cognitive models built on top of the former two [2], [9].

At the Cognitive Robotics Group at the Department of Computer Science, Humboldt-Universität zu Berlin, this project has been going on for about three years ([4]).

II. The quadrotor system

Our technical approach comprises of three basic aspects. Our *hardware* is based on the German Mikrokopter [1] kit with various custom extensions to provide additional onboard computing resources and sensors. We are so far using embedded Linux boards such as the Gumstix[1] and Beagleboard[2] OMAP3[3] prototyping systems. These provide sufficient computational power while being lightweight in physical dimensions, energy consumption and on the budget. In addition we are using custom sensor acquisition glue circuitry, infrared and ultrasonic rangers and a panoramic camera. The camera is a standard USB webcam with the Sony Bloggie panoramic lens attached [5] as can be seen in figure 1.

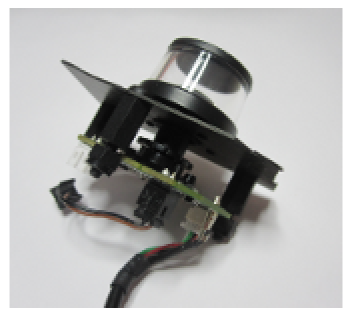

Fig. 1. Modified webcam with omnidirectional view.

For the *software* part we need a modular and lightweight framework for the onboard processing which enables rapid prototyping and is sufficiently open to concede to yet unknown problems. With the third generation of such frameworks we have arrived at MAVHUB [8] which provides exactly that and integrates the MAVLink [7] communication protocol to enable access to a wider toolset.

The *methodology* employed is a basic reactive architecture. The current controller modules' internal structures are strongly based on heuristics.

This system serves as the basis for the bio-inspired navigation experiments described in the next section.

III. Navigation experiments and results

We are currently testing two different navigation strategies as prerequisites for bio-inspired autonomous navigation.

A. Altitude control

The basic design for an altitude controller on top of attitude control including sensor fusion via a Kalman

[1] Gumstix Verdex Pro X6LP, Gumstix Inc., http://www.gumstix.com/product/verdex-pro
[2] Beagleboard, Texas Instruments, http://www.beagleboard.org
[3] OMAP3 Processors, Texas Instruments, http://www.ti.com

filter and downstream PID controller that has been prototyped in simulation has been implemented on the target hardware including utilisation of multiple sensors for distance and altitude measurement. This was facilitated by a working multi-component deployment setup including microcontrollers, embedded Linux, modular controller framework and debugging tools.

To take advantage of recipe based PID controller tuning on the physical robot we have implemented a system bumping controller to determine controller gain, dead time and integration time.

We have shown that a reactive controller with sufficient performance to control the vehicle altitude can be realised within Linux. This layer can in principle be plugged into any quadrotor kit providing basic attitude control capabilities.

As a consequence our quadrotor can be position controlled in the vertical dimension (see figure 2) which is supposed to serve as a basis for further vision based experiments.

Fig. 2. Four consecutive frames of a video of the flying robot.

B. Visual homing

Visual homing describes the ability of animals to return to previously visited sites using information from the visual senses. One class of visual homing methods are based on snapshots. Snapshots are stored representations of the visually perceived environment that can be compared to determine a homing vector for reaching an earlier visited site from the current location. The homing vector indicates the direction to travel for reaching the desired goal. Warping [3] is such a snapshot based method. The term warping relates to the distortion of an image in order to approximate it to another stored snapshot. The best match yields information about the movement parameters resulting in the current location. The algorithm requires the processing of panoramic images for access to the entire angular field.

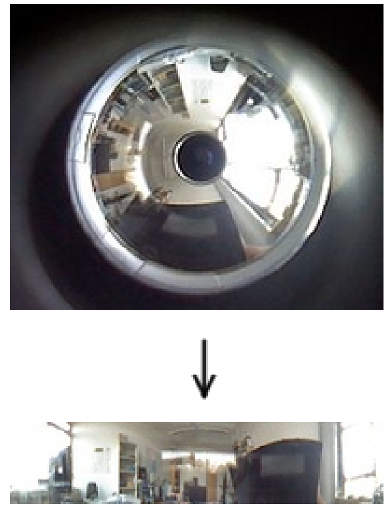

Fig. 3. Original image and its rectilinear projection (panoramic image).

In parallel to altitude control we have pursued the development of a warping implementation on the target platform. This included several steps. The first problem was to deal with the limited computational power of the embedded Linux boards as compared to a standard desktop PC. To comply, we decided to use a slightly modified version of the reformulated 2D-Warping proposed by Möller [6]. The use of lookup tables in that method accelerates the relatively costly search in the original algorithm. This implementation was tested on high-quality images from external databases to verify the post-optimisation accuracy.

The next iteration of adding factors that limit the accuracy but are necessary for onboard realtime performance was testing the target camera system. The camera delivers strongly reduced image quality compared to earlier tests (see figure 3). Despite, the results were still quite promising. In an offline test at this stage we got angular errors on average below 10°. This motivates us to further pursue this approach since warping is expected to still perform sufficiently well up to errors of a magnitude of 45°, theoretically even up to 90°.

In the offline warping experiments described above, actual altitude control could be neglected up to this point. Height above ground in above experiments was fixed at 1m. The challenge now consists in fusing altitude control and warping in one realtime process because warping further requires that all snapshots are taken at approximately the same vertical position.

IV. Discussion

Resulting from the work outlined above we are planning to pursue the following experiments.

The actual fusion of the altitude controller module (AC) and the standalone warping (W) module requires further breakdown of the procedure into several isolated steps.

The first of these steps would entail something like the following. Four closely spaced positions (order of magnitude 1-2m) will be approached with active altitude control and a series of snapshots taken. These snapshots can be analysed offline to evaluate the image series with regard to the influence of airframe stability (attitude and vertical noise), vibrations and other factors not yet accounted for on the performance of warping.

A second step in the overall direction is the realisation of position-hold functionality based on warping (micro-homing). The helicopter is supposed to hover on a spot with minimal lateral deviation. If this behaviour can be made robust under disturbances, many key factors needed for homing behaviour with warping would be in place.

For simplicity's sake, control will be broken down into yawing and translational elements. One particular expected problem is determining the threshold in image distances above which translation has to be effected after yawing. One important challenge in the dynamics is measurement noise and the individual malign noise characteristic which is due to different sensor types and physical principles. Overall, as can be expected, the hand-crafted solutions are brittle concerning both specific robot configurations as well as the transferability to other robots of similar, but not identical, setup.

As a consequence we think it is necessary to realise online adaptive mechanisms for tuning various parts of the system. Some of the hot-spots for the application of such mechanisms are, for example, the treatment of sensor signals in preprocessing (validation) and model-free controller tuning. These are but some prerequisites for robust behaviour in unknown and dynamic environments which is so splendidly displayed by even the tiniest biological organisms.

Acknowledgements

We thank everyone who has contributed to the quadrotor navigation project in the past, in particular Ferry Bachmann, Carsten Huhn and Michael Schulz.

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