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# The International Micro Air Vehicle flight competition as autonomy benchmark

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## I. INTRODUCTION

The development of air vehicles with competitions has a long history [1]. The first Micro Air Vehicle competition was organized in 1997 at the University of Florida, the same year that the first RoboCup was organized in Nagoya, Japan [2]. From 1997 to 2006 (except 2003) the size of the Micro Air Vehicles (MAVs) was reduced. Yet, with the reduced size it became also more and more challenging to operate and navigate those vehicles. Since 2007 autonomy in the control of the vehicles became more important; this resulted in an increasing score bonus in the rules.

This paper describes some of the progress made on autonomy inside this competition.

## II. AUTONOMY IN THE RULES

Since 2007, the Micro Air Vehicle competition consists of an indoor and outdoor mission [3]. For the outdoor mission the designs concentrate on dynamics, for the indoor mission the focus is more on autonomous flight. In this paper the indoor mission is taken into account.

The equation to calculate the score inside the competition evolved during the years, as indicated in Table II. In those equations, the autonomy is indicated by variable  $\alpha_K$ . The variable  $\alpha_K$  indicates an increasing autonomy factor. As an example, the level of control with the corresponding autonomy factor are given in the table I (from the most recent competition rules<sup>1</sup>).

Additionally, there is also a penalty factor  $e_K$ , which has value  $-2$  in the case when external aids such as visual markers are used. Other factors used in the score calculation in Table II are the points that can be gained with tasks  $T_K$ , the size of the air vehicles  $L$  (measured along the longest diagonal), the maximum size of an air

Level of control	$\alpha_K$
<b>Video based control:</b> control of the MAV is manual (from complete manual control to attitude stabilized control)	1
<b>Assisted flight control:</b> the navigation is not completely autonomous but the low level control is augmented by additional controls (such as collision avoidance or hovering based on laser scanner or optical flow)	4
<b>Autonomous flight control:</b> the navigation is completely autonomous but the operator is controlling the mission and the payload, processing perception, and making decisions	6
<b>Autonomous target detection:</b> the navigation and decision making is not autonomous but the detection and processing of the targets is automatic	6
<b>Autonomous mission control:</b> not only the navigation but also the detection and decision making is autonomous, without assistance of the operator	12

TABLE I. THE AUTONOMY FACTOR  $\alpha_K$  AND THE CORRESPONDING LEVELS OF CONTROL (COURTESY<sup>1</sup>).

vehicle allowed in the competition  $L_{max}$ , the innovation factor of the design  $D$  and finally the quality of the presentation  $P$ . The following table was collected from rule documents that were still available at the original competition site, from pages of teams which participated in these competitions or collected via the WayBackMachine initiative<sup>2</sup>.

The rationale behind this scoring formulae is that robots with a low autonomy factor  $\alpha_K$  have to demonstrate a much higher performance than robots with a high autonomy factor. For instance, one of the tasks during the indoor competition is to make as many loops between two landmarks. Robots which were manually controlled had to fly 12 times as many loops as robots which were fully autonomous.

For the upcoming competition in 2013 it is explicitly encouraged to collect as many points by collecting those points by multiple cooperating robots active at the same time in the same area. To encourage (semi-)autonomy, there is this year also a new score based on the operator factor  $O = \text{number of MAVs}/\text{number of mission operators}$ .

<sup>1</sup><http://imav2013.org/>

<sup>2</sup><http://web.archive.org>

Year	Score
2007 <sup>3</sup>	$\sum_{K \in tasks} \alpha_K \times T_K (2 - \frac{L}{L_{max}})^3$ with $\alpha_K = (1, 2, 6)$ and $L_{max} = 500mm$
2008	$\sum_{K \in tasks} \alpha_K \times T_K (2 - \frac{L}{L_{max}})^3$ with $\alpha_K = (1, 2, 6)$ and $L_{max} = 1000mm$
2009 <sup>4</sup>	$\sum_{K \in tasks} (\alpha_K - e_K) \times T_K (2 - \frac{L}{L_{max}})^3$ with $\alpha_K = (1, 2, 6, 12)$ and $L_{max} = 700 - 800mm$
2010	$\sum_{K \in tasks} \alpha_K \times T_K (2 - \frac{L}{L_{max}})^2$ with $\alpha_K = (1, 2, 6)$ and $L_{max} = 1000mm$
2011	$\sum_{K \in tasks} (\alpha_K - e_K) \times T_K (2 - \frac{L}{L_{max}})^3$ with $\alpha_K = (1, 6, 12)$ and $L_{max} = 700 - 800mm$
2012 <sup>5</sup>	$\sum_{K \in tasks} (\alpha_K - e_K) \times T_K \times D \times (2 - \frac{L}{L_{max}})^2$ with $\alpha_K = (1, 6, 12)$ and $L_{max} = 1000mm$
2013 <sup>6</sup>	$P \times \sum_{v \in vehicles} (\alpha_v - e_v) \times T_v \times \frac{1}{L}$ with $\alpha_K = (1, 4, 6, 12)$ and $L$ in $m$

TABLE II. THE DEVELOPMENT OF THE SCORE-FUNCTION DURING RECENT COMPETITIONS.

### III. PROVIDING AUTONOMY

As indicated in [4], is providing autonomous navigation to a small flying robot still a challenge. For a flying robot, doing nothing is already a task that has to be actively maintained. Stabilized hovering can be accomplished by combining control loop based on the robot's internal sensors and an external reference. For the popular AR.Drone platform the external reference is a downward looking camera, with a feedback loop based on optical flow [5]. Because the lifting capacity of a flying robot is limited, the sensor suite of the robot is also limited. In practice one can only fall back on an on-board camera. A camera is a relatively light sensor which provides a large amount of information, which can also directly be used by human operators.

Camera-based autonomous flight can be accomplished in two different ways: model-based and behavior-based. In the model-based approach the full state of the MAV (3D position, pitch, yaw, and roll) is estimated. Such a state estimate can be obtained by using a 3D model of the environment, which can either be given (Visual Localization) build up on the fly (Visual Mapping). Yet, most of the algorithms are computational so intensive that they cannot be executed on a processor carried by a MAV.

Behavior-based approaches do not try to maintain a model, but focus on coupling the right responses to incoming visual inputs. Typically, this coupling is not done directly, but by recognizing certain properties in the stream

of images. This approach is often called bio-inspired, because also in the visual cortex of the brain different areas are sensitive for different properties (such as direction of motion of visual patterns as lines and textures) [6].

In this paper examples of both approaches which are applied to navigate autonomously during the IMAV competition.

### IV. MODEL-BASED APPROACH

The first demonstration of Visual Localization during the IMAV competition was performed by the PixHawk team [7]. There localization was based on artificial features from the ARToolkit+ which were placed at known 6D-positions on the ground of the indoor arena. The algorithm makes use of the pitch  $\theta$  and roll  $\phi$  estimates from the inertia sensor to warp the images such that they are fronto-parallel with respect to the ground plane. The result is a 2-point algorithm [8] to estimate the translation in the remaining  $x, y, z, \psi$  directions.

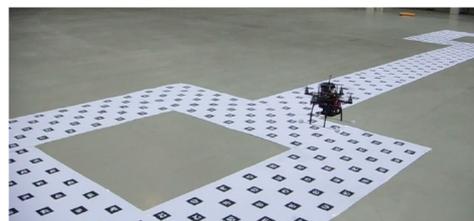


Fig. 1. The PixHawk flying an 8-figure during the IMAV 2010 competition (Courtesy [9]).

The markers of the ARToolkit+ contain a 2D binary code, consisting of both the marker ID and an indication of the correct orientation of the marker. So, those markers are not only relatively easy to detect, but also have a unique signature. With this setup the PixHawk team was able to complete two rounds of autonomous flight<sup>7</sup>.

#### A. Localization on natural features

At the 2011 competition the same capability was demonstrated, but this time without the aid of artificial markers. In this approach all parameters of an estimated 6D-position are used to warp the image onto the ground plane, which is a full perspective correction. In this image the Speeded-Up Robust Features (SURF) [10] are extracted; features which are invariant with respect to rotation and scale. In the setting of the 2011 competition the recognized features were mainly the colored lines used for different sports in the gym. Those features are matched against a feature map: a map learned from previous observations with in each grid-cell the feature with the highest response is stored.

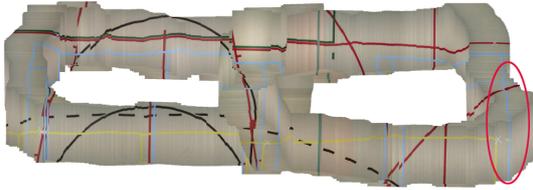


Fig. 2. The map generated by an AR.Drone flying an 8-figure after the IMAV 2011 competition [11].

The result is that during the first passage a visual map (see Fig. 2) of the ground of the indoor environment (a gym) is created which can be used in successive rounds. Note that the map shown in Fig. 2 is a texture map which can be used for human navigation and not the features (which are not so easy human interpretable) which are used by the robot. In the visual map small errors are visible in the perspective transformation, but those errors are mainly cosmetic. For navigation purposes this visual map is good enough. When needed, the visual map could be postprocessed by a mosaic algorithm as demonstrated in [12]. With this model-based approach the UvA team

was able to complete two rounds of autonomous flight<sup>8</sup>.

#### V. BIO-INSPIRED APPROACH

An example of a bio-inspired approach applied in the IMAV competition can be found in [13]. In their approach an edge detector is combined with motion information provided by elementary movement detectors (EMDs) [14]. The vision systems of flying insects are exquisitely sensitive to motion, because visual motion induced by egomotion can tell the animal much about its own motion and also about the structure of its environment [15]. EMDs use spatially separated inputs with a certain delay in time to produce a measure for the motion in a specific direction. The use of EMDs is especially useful for MAVs, since the flying task induces temporal and motion effects (which are known to cause the detection of spurious edges), ensuring that there is always activation from the EMDs.

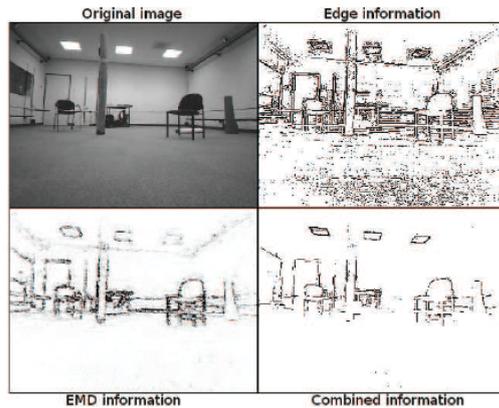


Fig. 3. Detection of the pillar for to fly an 8-figure after the IMAV 2011 competition (Courtesy [13]).

The result of combining the EMD algorithm with an edge detector the combined is that noise edges are filtered out. This algorithm is used to detect the two pillars which have to be navigated in the 8-figure contest. With this behavior-based approach the BioMAV team was able to complete three rounds of autonomous flight<sup>9</sup>.

<sup>7</sup><http://www.youtube.com/watch?v=83YR15vf718>

<sup>8</sup><http://www.youtube.com/watch?v=Zg8cF9TRk2U>

<sup>9</sup><http://www.youtube.com/watch?v=16jkwy2yRg8>

## VI. CURRENT CHALLENGE

This year the indoor challenge is extended with a number of mission elements; in total 7 elements which can be executed in parallel by multiple MAVs in a timeslot of 20 minutes.

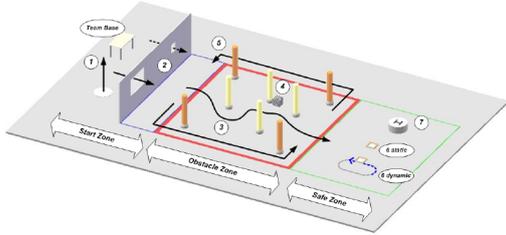


Fig. 4. An overview of the indoor mission of the International Micro Air Vehicle competition (Courtesy IMAV organization).

The mission elements consists of take-off, flying through a window, flying through an obstacle zone, target detection, follow a path, drop zone and finally a precision landing.

## VII. DISCUSSION

The rules in the Micro Air Vehicle have some resemblance with the rules applied in the RoboCup Rescue League [16]. Also at the RoboCup task points are collected by a team of robots and divided by the number of operators. In IMAV the autonomy factor is explicitly estimated by the jury. In the RoboCup Rescue Robot competition the autonomy factor is implicitly estimated; the environment is divided into yellow, orange and red areas. In the easiest environment (yellow) only points can be scored by fully autonomous robots.

## VIII. CONCLUSION

The Micro Air Vehicle provides a platform with a consistently shrinking size, forcing researchers to develop algorithms which work for 3D navigation with the limited resources which can be carried by the small air vehicles.

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