Dynamic Pattern Utilization for Automatic UAV Control Support

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***Abstract*—Within the research done at Fraunhofer IOSB in Karlsruhe in the area of civil security, various types of sensor/sensor systems, ground vehicles and Unmanned Aerial Vehicles (UAVs), have been used in the project AMFIS for some years. When it comes to aerial situation overview and reconnaissance, the research is focused primarily on electrically operated Vertical Takeoff and Landing (VTOL) systems which can be operated easily by police or rescue forces on account of the simple use and the good maneuverability even during applications in urban areas. One of the main research intentions of AMFIS is the further reduction of workload for the operator in scenarios where multiple and complex networks of different sensors and sensor carriers are used. That leads directly to the need for a high level of automation of the single sensor carriers. To further improve this automation the use of a dynamic and adaptable ground pattern as well as the detection and extraction of the information content of the displayed ground pattern onboard a flying vehicle is examined. The central objective of this investigation is the technical advancement of the dynamic ground pattern and the evaluation of the present test results as well as the use limits and the possibilities of the presented solution.**

Keywords-automatic UAV guidance; adaptive pattern detection; security and reconnaissance; visual communication; civil rescue forces

I. INTRODUCTION

As for the technological advance today, there are many systems and sensors to support rescue forces in their work to manage natural or manmade disasters. One focus of the research done at Fraunhofer IOSB is the application of modern sensors and sensor carriers to support police and firefighters in such situations. The project AMFIS [1] is concerned with developing an adaptable modular system for managing heterogenic mobile, as well as stationary sensors. The main task of its ground control station is to serve as an ergonomic user interface and a data integration hub between multiple sensors mounted on light UAVs or Unmanned Ground Vehicles (UGVs), stationary platforms (network cameras), ad hoc networked sensors, and a super-ordinated control center.

Within the amount of different sensor carriers already integrated in the laboratory test bed, micro UAVs, especially small VTOL systems, play a special role. An application of multi-rotor systems within rescue or security scenarios had become more realistic in recent years because of the rising usability and higher levels of automation and has in some cases already become reality. The research done in AMFIS focuses also on the extension of the application ability and automation of these sensor carriers. The aim is a ground control station permitting a single operator to control a complex heterogeneous reconnaissance system, not only sequentially by dealing with one sensor carrier at a time, but in parallel with reduced workload and supported by a high level of automation.

Our experiments have shown that the achieved level of automation is sufficient in most cases for the automated application of multiple sensor carriers with a minimum of operator interaction [2], [3], [4].

Only the landing process needs the unlimited attention of the user or a manual steering pilot because the navigation based on GPS and pressure sensors is not precise enough for a secure unattended automatic landing when space is the limiting factor.

Though, the automatic take off process of a GPS supported VTOL UAV is possible without supervision, however, the flight sequence is far away from an absolutely secure procedure and can be further improved therefore.

To remove this restriction and to protect the aircraft as well as the personnel and the material near the lift off and landing site, procedures were developed to provide an on board detection of a ground pattern to use this information for an exact automatic landing [5].

To use a static pattern, some problems have to be considered. Flying on different altitudes, the size of the pattern varies and a partial coverage of the pattern is inevitable on low altitudes making it hard to provide constant pattern detection. In addition, we wanted to use the visual information to add a new communication channel to control the UAV. For these reasons, the basic detection algorithms were designed to be also capable of detecting different patterns and to extract additional information from the ground pattern as for example deviation from the approach path or the direction and speed of a potential movement of the landing platform (if, e.g., mounted on a vehicle).

II. RELATED WORK

With the advance of the technological progress, UAVs can be successfully used for more and more applications.

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Hence, during the last 10 years, varied research results concerning UAV-swarming, independent navigation behavior, sense-and-avoid procedures and also work within the topic of autonomous or automatic landing and lift off were published. Within the field of research about the automatic landing of a VTOL UAV, the principle of using a ground pattern and visual pattern recognition for navigation and position extraction has been treated extensively. The usability of this approach is undoubted according to the achieved success and the application ability of such a system is beyond all questions.

S. Sharp et Al. [6] presented a test bed for onboard detection of a defined ground pattern using Commercial Of The Shelf (COTS) camera and hardware components. Saripalli examines a very interesting application in [7] using a pattern detection algorithm on board of a small unmanned rotary aircraft. A theoretical approach to track and to land the UAV on a co-operative moving object is presented. Zhou et al. [8] as well as Yang et al. [9] examined the possibilities of an autonomous landing on a static "H"-shaped pattern. Especially, Yang pays special attention to the high noise immunity and the rotation independence of the detection algorithm. Xiang et Al. [10] describe very interesting set up with low-cost COTS components (IR Cam of the Wii remote). The components are used to build an active IR pattern for the positioning system of a multi-rotor UAV. Lange et al. [11] also address the landing of an UAV on a ground pattern. They concentrate on handling the problem of the discrete scaling of the pattern independent of the different flight altitudes of the UAV by introducing a special designed circular ground pattern. Through different circles, which are becoming smaller to the centre of the pattern, the algorithm is capable of detecting the landing site also during the final flight stage of an approach without the need to adapt the absolute magnitude of the pattern. A similar approach is followed by Richardson et al. in [12], describing the landing of an autonomous UAV on a moving ground platform by using a pattern detection algorithm in co-operative surroundings. As in [11], a multistage pattern, which enables the complete visibility of the pattern for on board recognition also at a low flight level, is used.

All these researchers have shown good success in addressing very similar purposes. However, the suggested solutions suffer from some limitations as for example the restrictions due to the missing discrete pattern scaling during landing and takeoff. Additionally, we assume that each static mark approach will react on a pattern-like natural or man-made structure with miss-interpretation or detection errors. The dynamic pattern introduced in this research allows the construction of an additional communication link to the UAV and, besides, solves problems which are not handled yet and therefore differs from the present proposals.

III. Application Scenario and Motivation

One of the central application scenarios of the AMFIS system is to deal with the support of rescue forces in disasters or accidents. The varied application of different sensors on board of a UAV can provide support for the rescue forces and make their work more safe and efficient. Derived from the experiments done with the AMFIS system, the missing capability of the UAVs used within these experiments to precisely take off and land automatically on a designated position was identified as one of the main challenges for the professional application – especially when multiple UAVs are deployed at the same time. To deal with this problem the pattern recognition was developed and tested with a UAV system experimentally.

A dynamic pattern is not necessary compelling for the solution of the primary problem and quite good results were achieved using non-dynamic static patterns. Indeed, a dynamic pattern offers additional advantages which extend the application possibilities of such a system. Just by using the access to an, in principle, almost unlimited pool of different signs and symbols, the abilities of a pattern concept can be clearly enlarged. By that, the detection capability of the algorithm is not limited to the pure localization of the pattern any more. It can be extended by the capability to extract information content hidden within a detected pattern. Besides, a dynamic pattern still offers some other advantages. As already Lange et al. [11] stressed out, an essential problem within using ground patterns originates from the detection of a static pattern at different flight altitudes. Even when using a fish-eye lens during an approach of the sensor to the pattern, the probability rises that parts of the pattern are not grasped by the sensor because of the limited aperture angle and the increasing appearance of the image or pattern. The use of a dynamically adaptable pattern allows resizing the shown pattern. Thus, the size of the pattern can be adjusted matching the current flight altitudes raising the chance that the sensor is capable of viewing the shape completely. Though the algorithm is designed to be rotation and scale independent, nevertheless, the result quality of the detection algorithm can be further improved by aligning the orientation of the pattern with the direction of the UAV as well as considering its point of view and distorting its perspective.

However, the introduction of an additional visual communication channel provides even more advantages. Unfortunately the widely used radio data connections between UAVs and their dedicated ground stations can be very easily disturbed - intentionally or unintentionally. The detection of a used radio frequency can be done using COTS systems and even if it is not so easy to break into the communication to take over the UAV, in most cases it can be overlaid leading to a complete communication breakdown between the ground control and the aerial system. Using a visual communication system, interfering with the communication becomes more difficult because a potential disrupter stays hardly unnoticed if applying a permanent influence on the pattern providing ground platform.

IV. Adaptive Pattern and Onboard Detection Chain

The currently used setup for development, evaluation and demonstration of the conceptual design consists of the mobile AMFIS system as a control station, on the one hand, and the dynamic ground platform and the camera on board of the UAV for visual information extraction, on the other

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hand. A central object for further development is the technological realization of the dynamic ground platform which will be integrated into the AMFIS communication backbone for information exchange and to receive control commands in the future (see Figure 1).

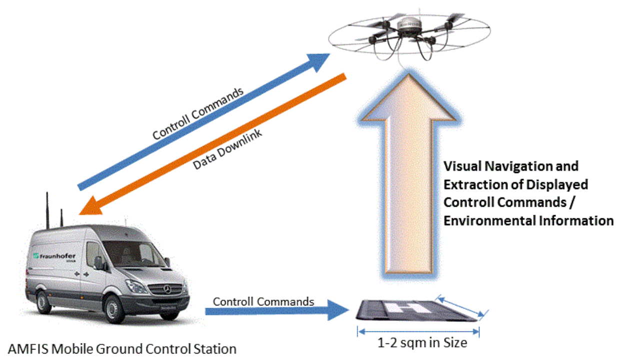

Figure 1. Sktech of the final target system.

For the initial non-dynamic testing of the algorithm, a static ground pattern with the shape of a white "H" on a black background was used. This test setup was designed to experimentally deploy the developed algorithm in a realistic test scenario under real conditions and environmental factors. However, on account of the long-term aim of developing and applying a dynamic pattern, the adaptability and expendability of the detection interpretation algorithm was emphasized. Hence, the developed dynamic pattern should show exactly the same static pattern (a white sign on black background) to achieve the highest possible contrast in the first experiments. Because the detection should be functional under bad lighting conditions also, a mechanical solution with flipping parts was excluded. An additional requirement was the demand for a simple solution to display different symbols or patterns. To cope with this, different Light-Emitting Diode (LED) matrices were examined and tested for their suitability. The experimental used ground patterns are all slightly different in technology and size. The originally used prototype based on single low cost LED panels and reached a size of 65cm x 65cm. Tested under realistic conditions, it shaped up that the low cost image display matrix, which provides control over every single LED, is not suitable on account of the used Pulse Duration Modulation (PDM) and the low fixed refresh rate. The PDM controlled LED cause a flickering not visible for the human eye, but for the camera. Experiments showed that this flickering troubles the algorithm in detecting possible blobs for the pattern in the video.

To reach a non-flickering representation, small 3x3 illumination LED matrices were used and assembled to an 18x21 experimental matrix even smaller than the original test system (see Figure 2). This pattern matrix turned out to be absolutely flickering free and can, therefore, be detected by the algorithm as one structure without any problems. The second advantage is that the assembled platform was luminous strong and provided the capability to see and detect the ground pattern even in bright sun light.

But, on account of the restrictions of the used 3x3 LED pluggable modules as missing control technology, limited displaying possibilities, difficult handling and the need for a more flexible test bed, the current research in this project is focusing on the use of a commercial high-end LED display for outdoor application, which is suitable to solve the problems of the low-cost display systems and can be deployed as a fully dynamic pattern projecting ground platform. For the new testbed, a panel of 1.57 square meter of high end SMD (Surface-Mounted Device) LEDs was purchased and is about to be included in the experimental setup. This more advanced system is designed to allow also a detection of the optical signals at higher flight levels of approx. 30 – 80 meters due to its size.

In addition, the panel offers the possibility to control the single LEDs again. This allows to scale the shown pattern and to adapt it to the flight altitude of the drone. The full 1.5 sqm can be used for maximum scaling and, therefore, reaches a size that allows the pattern to be recognized at an altitude of about 80 meters. It remains to be examined whether a pattern extraction is still possible in this distance.

If the UAV approaches the pattern or reduces its flight altitude over the pattern, the scaling can be adapted and the size of the shown pattern is reduced. Therefore, the full visibility of the pattern can be guaranteed on a lower flight level. Nevertheless, a short distance between camera and LED screen, as it happens on every final landing approach, can be seen as critical to functionality, because the low distance to the projection screen (d<1 meter to the surface) leads to the detection of single LEDs or rows of LEDs by the camera. In this case, the process chain is no longer capable of finding a coherent pattern area on which a verification and classification of the pattern is possible. This leads directly to the conclusion, that a workaround or an extension of the process chain is necessary to obtain the precise navigation during the last seconds of the final landing approach.

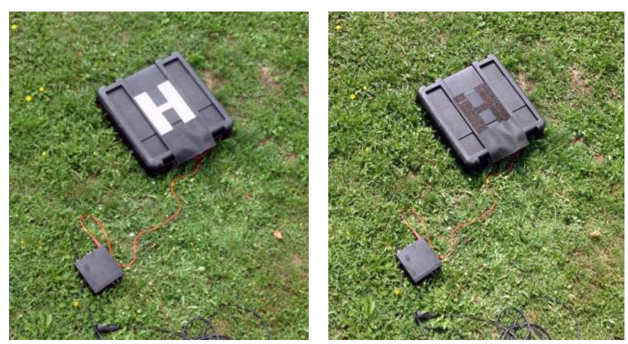

Figure 2. Illuminated an non-illuminated ground pattern.

The basic functions for adaptive pattern recognition have been reported in [5]. For the pattern recognition, there are two major tasks which must be solved. One task is the separation and extraction of possible pattern sub images from image sequences as pattern candidates for the recognition and interpretation of manmade landmarks. The implemented process chain with an adaptive threshold operation for this task works well and has not been modified for the present investigation. Another task is the recognition of patterns or manmade landmark images. The challenge of this task is that the onboard process chain for image evaluation must be robust, non-compute-intensive, expandable and fast. For that reason, we developed a so-called "zigzag" method which analyzes how many binary values of relevant parts of an object image are correlated with the expected values. The present investigation has shown that the method is easy to extend.

The algorithm inherits some serious advantages, as for example the rotation and scaling independence (see detection in Figure 4). At the same time it was designed not only to detect a pattern on the ground to calculate correct and GPS independent navigation information, but also to extract information from the different pattern sequences. The used "zig-zag" method has great advantages because of the fast and simple logic, used to recognize a single pattern. The procedure is quick and efficient and, hence, suited to deliver usable results with limited hardware capacity onboard which has been proven in the past attempts [5].

To achieve a sufficient information density, the different patterns have to be enlarged to reach the capability to transmit more complex information (see Figure 3).

Figure 3. Examples of used patterns.

This can be seen as a key feature of the dynamic pattern detection beside the improvement of the navigational information for the automatic landing. As already mentioned above, different patterns are shown at the same projection plane sequentially and can be recognized by the camera / algorithm on board the UAV. On the one hand, by flipping the patterns, errors occurring due to the detection of similarly looking natural structures should be avoided in future, because the system expects a regular change in the detected area. On the other hand, dedicated information will be linked to the single symbols. Orders or important information, as for example the current wind direction or a possible movement of the ground platform, can be encoded and transferred using the pattern sequences.

Therefore, the palette of used symbols was complemented with additional signs to extend the capability of encoding more complex information into a pattern sequence by switching between the introduced signs. Nevertheless, the used pattern pool is held small at the present time, because for every new introduced pattern the algorithm needs to be adapted in order to "learn" the new shape and to recognize it during the detection sequence. Additionally, an enlargement of the pattern pool also requires more logical operations during the scan process of possible pattern blobs found in the images which leads directly to an enlargement of process workload during the classification of the pattern in flight. It remains to optimize the balance between size of the pattern pool (for information encoding) and duration of the pattern classification process.

V. RESULTS

With the application of a static pattern, the functionality of the algorithm and its suitability has been proven for the integration onboard the UAV under the aspect of the limited computing capacity within this mobile system. The work based on these results has shown furthermore that even a simple active pattern which is reduced in its adaptability and displaying capacities is capable of improving the detection process. In [13], the test construction was described proving that the theoretical concept is functional and such a system could be applied successfully. The main objectives of these tests focused on the suitability of the concept mainly under strong external light influence and the enlargement of the detection capability to more than a single pattern as well as the differences in the detection results of the algorithm under differently strong self-illumination of the ground pattern (see Figure 2).

These experiments have shown that the used matrix can cope also with direct solar irradiation and emits enough light to produce a homogeneous pattern detectable by the algorithm.

Because of the promising results, the next step is to improve the possibilities of the ground pattern. Due to some restrictions of the used LED matrices like a slightly too big pixel distance and the difficult control of the LED sub elements of the pattern, there is a need for a platform with a higher usability. Therefore, the current step is to change the technology of the ground platform to a highly efficient commercial LED display that comes with the capability of high brightness and low pixel distance as well as multi-color representation possibilities. This promises a further improvement of the test bed and allows extending the experiments to test a bigger number of patterns without additional expenditure.

For the onboard component a fish eye lens was selected in the presented work to increase the detection area on one hand and to generate a stronger distortion in the picture particularly in the edge areas with the aim to test the algorithm also under more complicated conditions on the other hand. We assumed that the pattern must always be clearly visible from the image sensor, independent of the flight level of the UAV during the in-flight detection process. Numbers and characters are good land marks, because they have a system behind them, and can be encoded with high information content. To test the generality of our algorithm and process chains for the landmark detection and pattern recognition, two ground patterns "H" and "L" were used. These two ground pattern consists of the same hardware and were assembled currently by manually re-plugging the 3x3 LED modules.

Figure 4 shows the results of the pattern recognition while maneuvering the sensor carrier over the landing site. The width-to-height ratio of the ground pattern and even their shape may be strongly distorted by the fish-eye and rotation motion. The process chain works also well with the ground pattern "L" that is also captured with the fish-eye lens. To avoid ambiguity in the pattern recognition, a minimal size of the detected object image was used. This means that small object images can still be detected and extracted, but they are not suitable for pattern recognition.

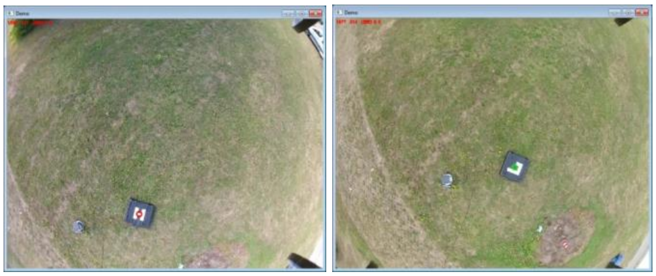

Figure 4. In-flight detection of shape "H" and "L" marked by colored circles at the center of the pattern ("H" is marked red; "L" is marked green)

Beside the fact that the algorithm cannot recognize the ground pattern in some frames the experiments showed that structures similar to the pattern can falsify the results. Though the used patterns were chosen that natural counterparts are rare, nevertheless, the attempts with static or partially static patterns showed that faulty detections are possible.

This leads to great danger for the flight system and ground crew and is therefore an essential point which needs to be solved in future works by introducing the final fully dynamic pattern projector.

VI. Conclusion and Future Work

On account of the conceptual change from a luminous-strong but not very easily to adapt matrix LED to an outdoor suited high-resolution LED display, the test system can be essentially extended in close future.

New possibilities are arising to improve the abilities of the algorithm in its detection quality and further extend its error tolerance as well as to develop completely new draughts for intercommunication between platform and UAV. For this purpose, the introduction of an initial recognition sequence which is visualized cyclic before each information transmission on the platform should be also examined.

Essential research topics will cover investigations in resolution and adaptation of the projected pattern in dependence of the altitude of the UAV. The focus will be to find the optimum way of scaling the pattern and identifying the thresholds at which a homogeneous pattern projection is no longer possible and how this problem can be avoided. That includes also tests about the practicability of different geometrical projections and rotations of the pattern and to determine the lowest possible angle of view to admit the most precipitous angles of approach. On account of the changed pattern technology a renewed test sequence to determine the efficiency of the high end panels with regard to the environmental conditions in particular to the solar irradiation has to be conducted. Due to the extended capabilities new possibilities of interaction have to be evaluated. The investigation of color coding as well as a negotiation or automatic calibration of the pattern can provide interesting new capabilities. For example, the adaptation of the luminous strength would be conceivable as a reaction to the current environmental conditions taking into account the feedbacks of the drone forwarding the information which kind of pattern coding can be recognized with the highest success rate.

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