Dynamic Pattern Development for UAV Navigation Support

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Abstract—**Electrically operated Vertical Takeoff and Landing (VTOL) Unmanned Aerial Vehicle (UAV) systems are used for aerial situation awareness and reconnaissance for civil security because they can be controlled easily on account of the simple handling and the good maneuverability even during applications in urban areas. The applications of such systems for rescue purposes strongly increase and, therefore, the need for professional support systems arises steadily. Takeoffs of a VTOL UAV system and in particular the landing have no meaning for the quality of a reconnaissance operation, but require the undivided attention of the operator. To automate takeoff and landing, the concept of a dynamic ground pattern for position correction and communication is suggested. The developed procedure is drafted and the advancement of the basic pattern projecting technology to two different working prototypes is described. The suitability of the prototypes is examined and reviewed. Main focus, in this occasion, is on the comparison of the different pattern projecting technologies to provide a statement about their strengths and weaknesses.**

Keywords-automatic UAV guidance; pattern projector; pattern detection; visual communication; civil rescue forces.

I. INTRODUCTION

As already illustrated in [1], there are various 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 rescue forces in such situations. The project AMFIS [2] 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, Unmanned Ground Vehicles (UGVs), stationary platforms (network cameras), ad hoc networked sensors, etc. 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. The further extension of the application ability and the computer-guided-control of these sensor carriers is also within the focus of research done in the AMFIS project. 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 in the past 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 [3][4][5].

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

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 in most cases not precise enough for a secure, unattended, automatic landing when space is the limiting factor.

To remove these restrictions 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 visual detection of ground pattern to use this information for an exact automatic landing [6].

However, using a static pattern, some problems and limitations have to be considered. Flying on different altitudes, the size of a static pattern varies and a partial coverage of the pattern is inevitable on low altitudes making it hard to provide robust pattern detection. To cope with these problems we extended the concept of using a visual fix point to provide a safe landing by introducing a dynamic pattern that can changes its representation in size and content. Therefore, it can be adapted to the altitude of the UAV and reduces the detection of false positives by an addition logical level within the detection process. In addition, dynamic patterns can be used as a communication channel to control the UAV.

For these reasons, the developed basic detection algorithms were designed to be 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).

The Introduction will be followed by review of related research in the field of automatic UAV landing facilitating pattern detection systems. Section III is describing the application scenario and the addressed problems in detail, followed by the subsumed results in Section IV on the original pattern recognition. Section V is introducing the main topic of this paper dealing with the development of different dynamic pattern techniques to create an advanced test bed that allows an intense validation of the overall concept. This is succeeded by an assessment of the created pattern systems in Section VI. Finally, the results are recapitulated in Section VII followed by conclusion and future work.

II. RELATED WORK

With the advance of the technological progress, UAVs can be successfully used for more and more applications. 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 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. This application of visual extraction poses a special problem within the field of image exploitation. Procedures for the processing and recognition of structures in a video stream are used in different areas professionally. For example number plate recognition or the automatic detection of deposit bottles in sorting machines should be mentioned. However, in most applications position, distance and orientation of the pattern to detect can be forecasted very exactly reducing the complexity of the application. This does not apply when using pattern recognition as a navigation support on board a moving UAV. The pattern can become visible in different distances, dimensions and rotations and, hence, poses a more complicated problem in the field of image exploitation. Nevertheless, the usability and applicability of this approach is undoubted according to the achieved success.

S. Sharp et al. [7] 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 [8] 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. [9] as well as Yang et al. [10] 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. [11] describe a 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. [12] 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 [13], describing the landing of an autonomous UAV on a moving ground platform by using a pattern detection algorithm in co-operative surroundings. As in [12], 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, each static pattern approach can 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.

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 be used to acquire important reconnaissance information to make the work of the people in the field more safe and efficient. Derived from the experiments done with the AMFIS system, the missing capability of the UAVs used within these scenarios 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.

The endurance of electrically operating UAVs is limited and in most cases several take offs and landings become necessary in order to fulfill the mission. In these flight phases the UAV must be supervised and neither the operator nor the UAV can contribute to the mission's target. To automate these flight phases the navigation exactness needs be improved. A visually extracted geographical fix point at the landing position is, on this occasion, a promising start. The here presented draught is based on already achieved success with visually extracted patterns and extended to use dynamic pattern recognition with the aim to receive a more stable and reliable navigation support.

A dynamic pattern is not necessarily 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 functionality to extract information content hidden within a detected pattern. Besides, a dynamic pattern still offers some other advantages. As already Lange et al. [12] 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 could possibly 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. An optimized projection of the pattern considering not only distance but also the orientation and view angles is assumed to potentially reduce the load on the low-power on-board processor.

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. ONBOARD DETECTION CHAIN

The basic functions for adaptive pattern recognition on board the UAV have been reported in [5]. The implemented on board detection chain basically consists of two major tasks.

The first 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.

The second task is the recognition of patterns or manmade landmark images from the identified candidates. The challenge of this task is that the onboard process 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 within the selected region identified as a possible pattern.

The previous investigation has shown that the methods and the complete on board detection chain is stable, easy to extend and provides good results on detecting the patterns on the ground in different conditions.

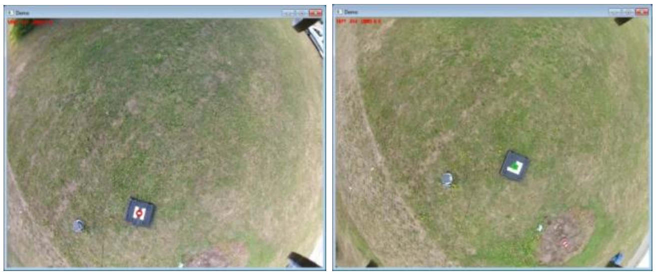

Figure 1. In-flight detection of shape "H" and "L" marked by colored circles at the center of the pattern ("H" is marked red; "L" is marked green) camera: GoPro Hero 2, altitude: 30 metres.

An important part in the first task of the process chain is the recalculation of identified possible patterns. These sub image regions are translated into a standard region. The algorithm inherits therefore some serious advantages, as for example the rotation and scaling independence necessary for an UAV application (see detection in Figure 1).

At the same time the designed is not limited to only 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. Using the detection of different signs in different sequences for creating a pattern language allows the transmission of reduced information form the ground to the aerial system.

Figure 2. Examples of used patterns.

To achieve a sufficient information density, the number of different patterns has to be enlarged to reach the capability to transmit more complex information by combining symbols (see Figure 2).

This can be seen as one other the key features 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 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 time and 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. ADAPTIVE PATTERN DEVELOPMENT

The currently used setup for development, evaluation and demonstration of the conceptual design was based on different simple pattern projectors to evaluate the concept and its functionality. The identified technologies that can be used to set up a working pattern projector needed to be consolidated in order to create a more flexible, adaptable test bed. The central object for further development is therefore the technological realization of the dynamic ground platform to create a complete working prototype, which will be integrated into the AMFIS communication backbone for information exchange and to receive control commands from the system in the future (see Figure 3).

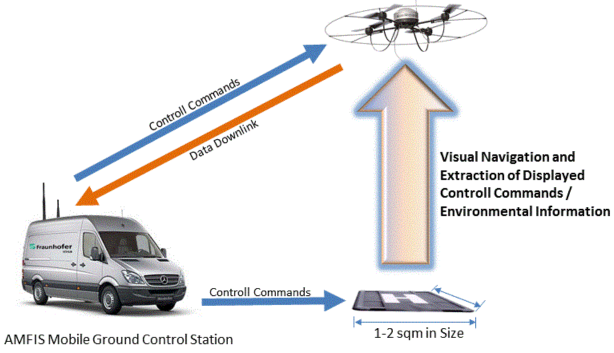

Figure 3. Sktech of the final target system.

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 (e.g., sunshine). However, on account of the long-term aim of developing and applying a dynamic pattern, the adaptability and expandability of the detection and the interpretation algorithms was emphasized. Hence, the developed dynamic pattern should show the same static pattern (a white sign on black background) as exactly as possible to achieve the highest possible contrast in the first experiments.

Because the detection should be functional under bad lighting conditions and the missing possibility to introduce new or adapted patterns in the future, a mechanical solution with flipping parts was excluded. It has been assumed that the final working system could need an extension on the pattern alphabet or a change within the available patterns when new demands arise. A simple solution to display different symbols or patterns in different representations and scaling needed to be found. To cope with this, different Light-Emitting Diode (LED) matrices were examined and tested for their suitability.

The experimental used technologies for dynamic 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 65 x 65centimeter. 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.

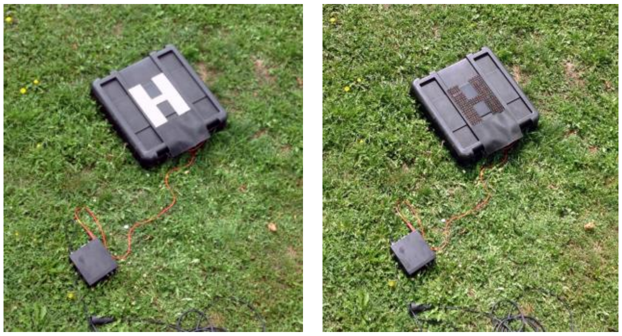

Figure 4. Illuminated and non-illuminated ground pattern.

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 4). 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.

The functionality of these different projection technologies were tested under different circumstances. In [1] it was shown that the developed algorithms in combination with the two described technological diverse pattern projectors are applicable for pattern supported navigation. Nevertheless, the validation of the overall concept for a final pattern projection technology is a central precondition for further advancements. Because different draughts for pattern projectors were pursued it is important to consolidate this technology and to transfer the knowledge from the validation process into a final technical draught. Based on the results of the present technological experiments two technology demonstrators were developed and tested. Both systems are based on matrix LEDs that can project different patterns. Indeed, they differ in the way the representation of the single patterns are generated as well as in their technical construction.

A. *Large Pixel Pattern Projector (L3P)*

The L3P (see Figure 5) is based on technical specifications of the 3x3 LED illumination matrixes also facilitated in the projector in Figure 4. The main difference to other tested matrixes is that the control of single LEDs to visualize certain forms or pictures is not their scope of application, but a constant full-area backlight illumination.

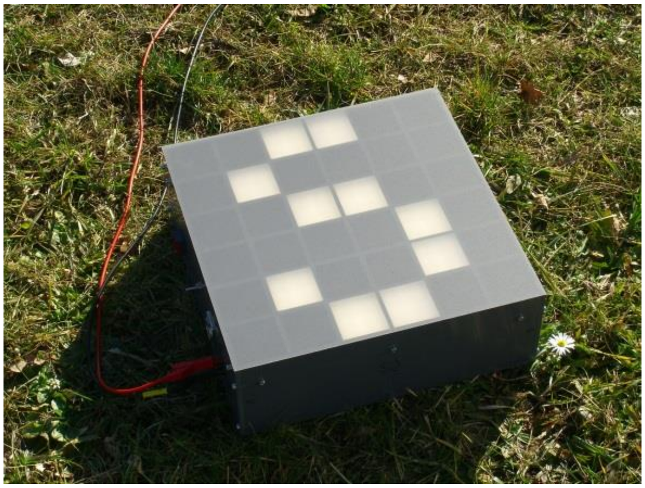

Figure 5. Large Pixel Pattern Projector (L3P).

The single modules are equipped with 9 LEDs, which can be either fully activated or deactivated. Based only on this technology a true-dynamic pattern projector cannot be realized. Hence, for the active pattern a projector module was developed, which includes several of the lighting modules, which can be switched on or off computer-controlled. The so designed pattern module consists of a total of 36 lighting modules and permits all possible permutations of illuminated and deactivated light fields controlled by the integrated hardware. Every single light field is separated with footbridges from the neighboring fields to allow a clean, sharp-edged projection. The projection screen is concluded with a diffusor, which compensates the relatively big distance between the single LEDs and prevents the covering of partial LED segments when the approach angles of an UAV are getting sharper.

In contrast to a fully adaptable pattern projector the ability of scaling the image is decreased by the size of the single pixels and the interconnected low overall resolution. On the other hand, originating from the diffusor and the size of the single pixels, it was assumed that less detection problems will arise during final or low flight phases.

B. *Flexible Advanced Pattern Projector (FlAPP)*

Beside design and construction of the L3P a second solution for a fully adaptable projection technology was developed. In opposite to the reduced scaling capabilities of the L3P the FlAPP should provide a high flexible pattern projection. An exact control of single LEDs is essential for a visualization of patterns in different scaling. For this purpose different high end LED panels were examined. As a main problem, on this occasion, it turned out that most LED screens suffer from a too low refresh rate. As a result of the flickering representations of the patterns the algorithms could not recognize the content and, hence, failed.

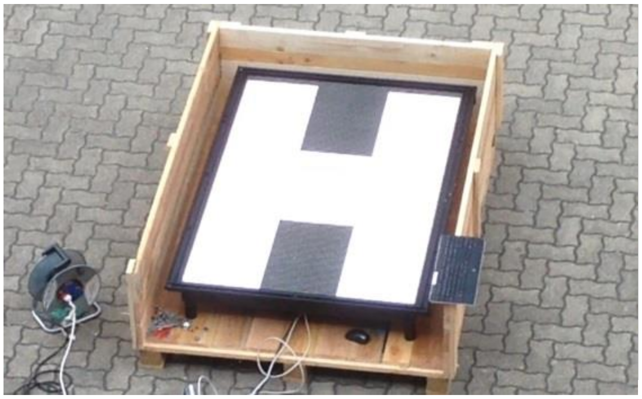

Figure 6. Flexible Advanced Pattern Projector (FlAPP).

The FlAPP was conceived as a LED panel build from SMD LEDs, which refresh rates were heavily raised with additional LED control technology to eliminate these problems.

VI. ADAPTIVE PATTERN ASSESSMENT

To further improve the development of a test system for the pattern-recognition-supported precision landing, the L3P and FlAPP had to be comparatively tested. By these tests under equal conditions both technologies become comparable to each other and can support a final technology decision or lead to a new development cycle to improve the test bed. Both draughts have their advantages and disadvantages, which were known partially in advance or were discovered in the draught-related test studies.

The L3P distinguishes itself by high contrast and angle independence by the accordingly scattering diffusor. However, it is limited in its scaling possibilities because the single pixels cannot fall short of a minimum of 45 x 45 millimeter design dependent. Therefore, the resolution is low with ca. 386 pixels per square meter. The big advantages are the directly supplied LED modules, which are not controlled by a cyclic refresh process and provide a non-flickering representation independent of the used camera system. However, in comparison the FlAPP provides by its more than 40-times higher pixel density of 15,683 pixels per square meter a better adaptability in the representation of single patterns and also in their scaling. In addition, the available test system is equipped with RGB pixels, so that test series in different frequency bands of the visible light spectrum become possible.

For the comparison tests of the developed pattern systems the demands for a functional projector were gathered and realistic scenarios within the scope of the common takeoff and landing routines were extracted.

Regardless of the type of control (manually or computer-controlled), the approach on the landing position in present flights occur accordingly to the same workflow. The UAV stays on a safe flight altitude, which can be assumed to be free from any obstacles within the operation area.

If emergency procedures after a communication loss or a low energy alarm are disregarded, the UAV returns for landing to its starting point or another geographical position specified by the user. If the UAV has reached its landing position on a safe flight altitude, the pilot or the computer reduces the thrust and the UAV is approaching the ground. None or only GPS based course corrections are occurring in the computer-controlled mode, while a manual flying pilot can adapt the descent in speed as well as in horizontal direction to provide a safe landing. Hence, the direct vertical approach to the ground pattern arises as a primary test scenario.

Beside the recognition of the pattern, the scalability of the patterns is one essential factor to be tested. Dependent on the selected EO sensors the minimum size of the projected pattern in different distances has to be determined in order to selcet a suitable scaling.

Beside the maximum height or distance between sensor and projector, the minimal possible distance is of big relevance. Due to the used algorithm the projected shape of the pattern must have an interconnected structure. If the shape falls into pieces because of a too big pixel distance, the algorithm cannot recognize the pattern anymore and the pattern detection fails. This happens because of the adaptive threshold operation when the algorithm is searching for possible pattern blobs in the image. If parts of the pattern are disconnected to the rest, they will be detected as stand-alone-blobs. The detection tasks will try to recognize them and will fail. Particularly for the application of the FlAPP this problem is of central importance as a diffusor is absent and perhaps would have to be subsequently mounted to close possible appearing gaps at short distances between camera and projector. But also the L3P design has caused narrow dividing footbridges between the pixels that could limit the detection robustness.

Beside the primary task of validating the pattern technology concerning a functional direct vertical landing, the enlarged abilities of the draught are also to be examined. The above described scenario implies a low angle divergence during approach. However, if the possibilities of the used UAVs to adapt the optics horizontally as well as vertically are taken into account, sharper angles of approach need also to be considered. This scenario slightly adjusts the demands for the pattern technology concerning the homogeneous radiation of the LEDs or the diffusor. It was assumed that the L3P will provide a clearly steadier image projection on account of the diffusor whereas the FlAPP could suffer from color and intensity changes in different views. Hence, the experiments were extended to achieve a simple comparison between the projectors on account of different view angles. The perspective distortion of the patterns was neglected and is of minor importance as the algorithm is scale and rotation invariant.

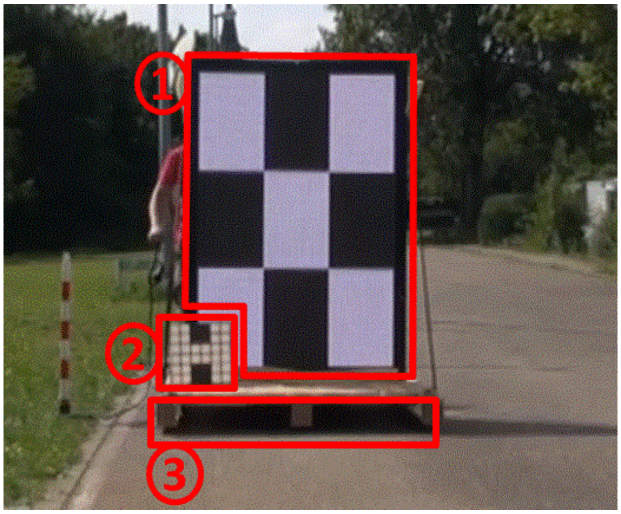

Figure 7. Test set up: FlAPP (1), L3P (2), mobile plattform (3).

In preceding test cases, enlarged flight experiments had already proved basic functionality of the concept facilitating illuminated but non-dynamic patterns. The knowledge and results from these experiments influenced the development of the L3P and the design of the FlAPP.

Particularly the development of a suitable diffusor that provides enough dispersion on the one hand and a low damping rate on the other hand, so that recognition is still possible under direct solar irradiation, is decisive for the functional L3P.

All initial test series were conducted under the premise of realistic application surroundings. Therefore, the pattern projectors were installed horizontally on the ground. All test recordings were done on board of a UAV with direct solar irradiation on the pattern. This modus operandi allowed checking and validating the design and functionality of the approach (see Figure 1).

The subsequent test series were focused on the applicability of the selected cameras as well as on the evaluation of the different pattern projector technologies.

In order to be able to compare the well-chosen electro-optical sensors, the image recordings must be done at the same time from the same position in identical distance and lighting conditions. As the UAV chosen as target platform is not capable of carrying all cameras and their recording equipment, the experimental set-up was transferred for simplicity reasons from a vertical test bed into a horizontal one.

For this purpose the FlAPP was installed upright on a mobile platform. This was not necessary for the L3P, because it can be moved easily from hand due to its small size and weight (see Figure 7: FlAPP (1), L3P (2), mobile platform (3)). A test track of a maximum of 50 meter in length was set up where the FlAPP as well as the L3P were recorded by the different electro-optical sensors in different distances. Beneath the direct view at the sensor, additional approach angles to the pattern projector were simulated by panning the mobile platform.

VII. RESULTS

Essential topics for the further advancement of the technology could be identified by the evaluation of the test series and the recorded data. The functional limits defined by design referred to an operational distance of 0 to 100 meters between projector and image sensor. The tested set up covered a maximum distance of 50 meters, the results for distances beyond 50 meters where calculated. For the distance tests the FlAPP was used as reference system because of its size and scalability.

Based on the acquired data the main restriction identified for the chosen approach is that the complete application range cannot be covered by a single camera system fix fixed optics under the addressed conditions. In average, using different image sensors and distances the pattern was recognized down to a lower border of 6% of the side lengths of the original image resolution. In dependence from sensor, optics and the size of the pattern, the possible maximum distances for a successful detection can be calculated therefore.

The scaling possibilities of the FlAPP allow adapting the pattern to the flight altitude of the approaching UAV. Particularly during deep flight phase this is vital, because it covers the most critical part of a final approach. Hence, within 0 – 5 meters above ground, special demands for the image sensor and the optics arise. Though, the pattern is reduced in size, however, for a successful detection it should not exceed 60% of the image until shortly before landing. A wide-angular optics is suitable particularly for the final flight phase. At heights of 20 meters and more above ground, these camera systems fail in delivering a suitable image for detecting the pattern. Hence, the application of a telephoto lens is unavoidable when the functionality should be also guaranteed in higher operation levels.

Based on the minimum side length of 6% and 60% as a maximum value, 10% and 50 % were used for the calculation of the final optics. The considered buffer should permit a safe detection even at the outer bounds of the specification.

A vario zoom optic is not always possible because of its weight and the low payload capacity of the UAV.

Based on the test results of different camera systems a camera of the company IDS-IMAGING, the UI-2230SE was selected for further testing. Based on the performance data the necessary focal length can be calculated. The sensor size of the UI-2230SE is 1/3” (*B*), 3.6 millimeter to 4.8 millimeter and 6.0 millimeter diagonal. Image distance (*b*), object distance (*g*), focal length (*f*) and object (*G*):

$$f' = \frac{g}{\frac{G}{B} + 1}$$

With the restriction of the minimum and maximum picture ratio a theoretical focal length of 24.4 millimeter arises for the distance up to 15 meter and 81.2 millimeter focal length for distances of 20 – 50 meter. A continuous coverage for 0 – 100 meter is not possible with these restrictions. Pushing it to the edge using 6% image cover as determined during the test, the full distance up to a flight altitude of 100 meter is covered.

TABLE I. FOCAL LENGTH FOR DISTANCE

Focal length	**Distance**						
	0 - 15	***15-30***	***30-45***	***45-60***	***60-75***	***75-100***	***100 +***
100.00			◨	🟩	🟩	🟩	🟩
80.00		◨	🟩	🟩	🟩	◧	
65.00		◨	🟩	🟩	🟩		
50.00		🟩	🟩	◧			
15.00	🟩						

Attempts in the infrared spectrum of light have proven that detection of the patterns is possible but not effective. As it has been expected, the radiation of the used LEDs in the infrared spectrum is near zero. Merely the up-warming electronic modules were recognized with a big delay. A change of the pattern projection needs therefore several minutes to become visible to the IR sensor. After switching off of the pattern the last indicated symbol is still detectable for some time. Using IR for the pattern projection is interesting but would need a complete redesign of the pattern projection technology. Available LED panels are equipped with LEDs for the visual spectrum of the light due to their application purposes. For a fully working IR panel the LEDs need to be changed into special LEDs emitting light in the infrared spectrum. Further experiments with IR are therefore expulsed.

The comparative test of the developed projectors L3P and FlAPP could be used to evaluate the basic design as well as the special stages of development. Besides, both pattern technologies could show their strength. However, the identification of possible weak spots and problems was important. As illustrated in Figure 8, unexpected side effects were detected on the FlAPP during the measuring campaign. Partly heavy Moiré effects could be observed in some recordings in dependence of the used camera, certain distances and view angles. Though the effects of the image interferences turned to be acceptable to the algorithm, or could be removed by known procedures like, for example, a combination of image dilatation and image erosion, nevertheless, such effects need to be avoided if possible to provide a more robust detection and to keep the workload of the on-board hardware as low as possible.

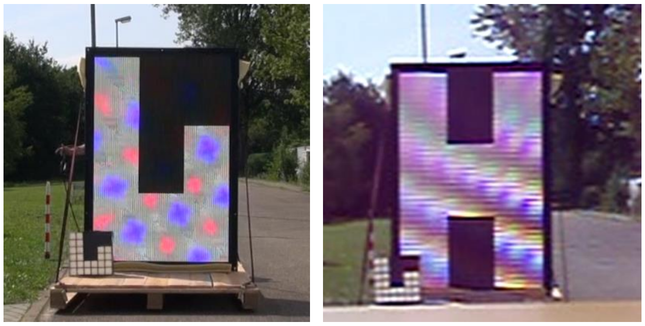

Figure 8. Moiré effects on the FlAPP.

We assume that the Moiré effects are originating from the overlapping of the matrix structure of the FlAPP by the matrix of the digital sensor. Therefore, the appearances of these effects are depending on distance and angle between camera and matrix LED. This phenomenon is strongly dependent to the combination of used image sensor, distance and angle. Hence, the appearance of such image interferences is difficult to avoid just by changing the sensor. The L3P does not show these effects on account of the fixed projection of the single large pixels and the distant mounted diffusor. Because of the pixel size and the steady light emission of the L3P the matrix is not filigree enough to generate Moiré effects by an overlapping with the raster of the image sensor. Tests have shown that the application of the same diffusor used on the L3P reduces the Moiré effects on the FlAPP to a minimum.

As expected, the scalability of the patterns proved to be the central functionality that can guarantee successful detection during the final landing approach. The L3P showed here its weaknesses, because the display of the pattern is of limited scalability. To deal with these problems, this technology requires the implementation of a special solution for the final approach sequence like introducing a new pattern consisting of a single white square (a single Pixel of the L3P when scaled to the minimum).

In addition to the internal factors, problems with the brightness of the projectors could be identified in the test. Originally it was assumed that detection problems will arise mainly in bright sunlight. The tests have not confirmed these concerns. But changing the conditions towards a poorer external lighting, some image sensors tend to catch a blurry representation of the pattern, especially at larger distances between projector and sensor. The pattern becomes indistinct to a single spot and thus cannot be detected anymore. The smaller the pattern (the greater the distance), the more intense is this effect, since fewer image pixels are accordingly covered by the pattern. At close range, this effect also occurs, but because the pattern is sufficiently large, the effect on the detection is low. The FLAPP is already equipped with an ambient sensor that can adjust the brightness to the external influence, but the sensor was not considered in the current test series. The L3P does not have such a sensor and therefore, needs to be upgraded.

Both pattern projectors have shown their strength and weaknesses during the test series. Based on the results the further development will focus on the application on the FlAPP as a final technology. But, because of its simplicity, the good handling and the low price, the L3P could also be updated and considered in future test set-ups.

VIII. CONCLUSION AND FUTURE WORK

In this paper the activities of Fraunhofer IOSB in the area of civil security and their relevance for a supporting application in emergency situations were explained. For this work the applicability of small VTOL UAV systems to support rescue forces with local reconnaissance were brought into focus; the importance of a further improved automation was described. The essential restrictions of this technology for a realistic application concerning the critical flight phases of take-off and landing were discussed. As a solution for these problems the application of pattern recognition on board of an UAV in combination with a dynamic pattern projector on the ground was suggested. Besides, this works is built on diverging scientific research in the area of pattern based VTOL UAV landing, the essential difference is the introduction of a dynamic, adaptive ground pattern, which can visualize different patterns in different scaling. Therefore, central problems of pattern-supported navigation can be solved with the proposed approach. The likelihood of a false positive on the basis of natural structures similar to the pattern can be drastically lowered when a pattern is confirmed only within a detected structured sequence of different patterns. Missing the pattern in low flight altitudes due to dimension problems are avoided until the touch-down because the patterns can be adapted in their size according to the flight altitude of the UAV. In addition, the pattern sequences can be used for a low rate data exchange. Thus, relevant information can be transferred to the approaching UAV, for example, a divergence of the landing path or special alignments or course corrections.

To develop a dynamic pattern, different LED technologies were examined and checked on their applicability. The functionality of the draught was checked by successful system demonstrations. The identified functional LED technologies were further examined and two operational prototypes were developed for extended operational tests. These prototypes were operated in parallel and recorded with different IO sensors. On the set up test-range, sensors and projectors were evaluated in defined distances. Based on this data and the detection results, statements about the future technologies concerning cameras and ground pattern were made and necessary changes in the approach were identified. In particular, the quality increases by a distant mounted diffusor, as well as the better luminous performance of the FlAPP will affect future works. Regardless of the pattern technology the detection algorithm is to be extended by the still missing pattern recognition for the new introduced patterns. Additionally, the development of a suitable pattern language as well as the safe ground pattern identification on base of pattern sequences has to be concluded.

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