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Free Fall Detection in UAV Missions

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ABSTRACT

This research paper addresses the designing of high speed free fall detection and primary trigger generation problem as a part of an in-flight emergency technology developments for unmanned aerial vehicles. The primary trigger is the very first to be detected and to be generated with high speed and accuracy in designing protection mechanism. This trigger indicates that UAV started falling. Sequences of resulting mechanism such as airbag inflation comes secondly. Speed requirement is a deterministic factor when the flight altitude is low. In this paper a high speed analog module is proposed to achieve the primary trigger and performed relevant validation tests on linear free fall and rotational free fall which covers the majority of free fall patterns. The positive test results verify the design as a primary trigger generation module for linear and rotational free fall detection in low altitude UAV missions or which could be enhanced with additional features to form more complex system of airbag inflation in UAV in-flight emergency technology development.

Keywords: High speed trigger generation, UAV in-flight emergency technology, UAV Free fall detection, UAV Airbag inflation

I. INTRODUCTION

Unmanned aerial vehicles (UAVs) gained much popularity in various applications recently. Development in-flight emergency systems also already became an important research problem. Deploying parachutes also already become popular in-flight emergency system. The quality of existing in-flight emergency systems is questioned for low altitude flight missions. In this research the targeted UAVs are popular multi-rotors, not fixed wings and VTOLs or quad planes.

Using popular terminology, UAV crash patterns could be considered as free falls, tumbles, flips and their combinations. Also could be more complex patterns of fall that are difficult to detect. One such example is that UAV is in a fall with non-gravitational acceleration, e.g. motors produce some amount of thrust during fall. When ignoring the effects of air resistance unless special cases such as already deployed parachutes or fall with some vertical force being applied on the object, fall pattern of multirotor UAV is a freefall, where by definition the force of gravity is the only acting force on the object during fall. The quantitative difference to the ideal could be addressed in engineering level up to a certain level when the approach to the solution become clear, e.g. during signal processing.

Geometrically, free falls can be grouped into linear free fall which is linear translation relates to fixed orientation, rotational free fall which the former orientation changes with related to axis and projectile fall which can be explained as vertical and horizontal planar translation. In all freefalls mention in this paper UAV is under gravitational force and not under other vertical forces. Projectile fall also produce similarities to rotational fall. Unless the UAV is designed exceptionally for acrobatic flight patterns, linear falls and rotational falls cover the majority and those fall could be considered as freefalls. Figure 1 illustrates and explains the terminology of the UAV fall patterns for which the triggers generated in this paper. From trigger generation view point it could be stated that non gravitational falls could be treated to some extent with threshold values.

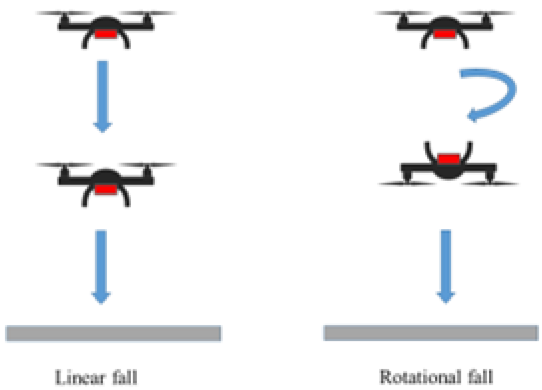

Figure 1. UAV free fall patterns in this research

To identify the type of free fall the UAV undergoes in addition to real time signal the information on orientation also required. As the engineering objective is to verify the fact that UAV is under a free fall but not the verification of which type of free fall the UAV is undergoing, the engineering problem could be further simplified into a threshold detection and trigger generation problem. The primary trigger is the result of this very first detection that the UAV started to fall and is the first element of an in-flight emergency system. Figure 2 illustrates the typical threshold values of signal.

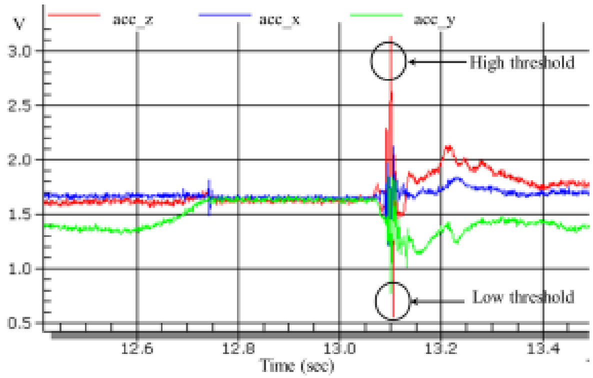

Figure 2. Typical Threshold Values

Speed is mission critical in designing solution for low altitude flight missions. As an in-flight emergency system example, in [1] auxiliary power unit is designed and tested for low altitude tethered UAV missions. The trigger in [1] is auxiliary power signal from UAV power conversion system and the resulting mechanism is switching the supply power to an alternate source during low altitude flight. In this in-flight emergency system trigger is considered as a result of a combination, the first of which is mentioned in this paper. Final resulting mechanism is airbag inflation.

In in-flight emergency system designs it is a normal practice to allow more time for resulting mechanism and save time on detection. Although not in-flight emergency systems but popular applications using free fall detection like typical hard disk protection applications, it is known to save more than 90% of fall time for protective mechanism. In this approach since the sensor dependency is reduced up to easy replaceable analog accelerometers. As reducing implementations restrictions and operation restrictions tilt sensors are opted.

As contributions to current knowledge including substantive developments, as well as theoretical and methodological contributions to UAV related technology, [2, 3, 4 and 5] are being referred. In [2] in-flight emergency products for UAV missions. In [3] fall detection approach for UAVs, [4] a contribution from application perspective and [5] from security perspective.

Organization of the rest of paper is as follows. In the next section the proposed design and related problems addressed. The validation tests on the proposed module are performed in linear free fall test and rotational free fall test sections. Finally the conclusions are drawn based on validation test results and enhancements are discussed. It should be stated that since this research is an in-flight emergency technology, proposed module is expected to be simple, stand alone and reliable. In this paper basic steps toward developing are discussed. Fully developed model by the author is presented in [9].

II. THE PROPOSED DESIGN

The following are basic design concepts that lead us to the featured product. Hence engineering problem simplified into a threshold detection and trigger generation problem as explained in the introduction, from signal processing perspective design includes signal comparison, trigger generation and latching.

First step is signal comparison. Rather than simple comparison of signals using comparators, difference between known threshold and the accelerometer signal is amplified before generate triggers to improve resolution on precision.

Even though this looks like a simple amplification for some readers, this step plays a vital role in our module. Technical merit of this amplification is that it enables the precision on triggering voltage. This overrides the operation uncertainties at low voltages comparison at application level. In [6, 7] this problem is explained and addressed. In this research we approach with a different application perspective. Artifacts of our solution comes with a slight hysteresis issue as illustrates in amplification test results in figure 4. As we are using the linear zone our amplification could be considered as a practical solution. Initial uncertainties as race conditions [8] are also to be solved during this design. Figure 5 illustrates a false trigger during start up the module. The following is a theoretical explanation on this amplification.

Difference amplifier is used where one of VA and VB becomes fix and the other becomes variable depends on threshold. If it is used as high threshold detection VA is fixed pre-known value VB varies. For low threshold detection it should be vice versa. The particular values for high and low thresholds are set empirically in this research, which is mainly sensor dependent factor. Figure 3 illustrates a typical difference amplifier.

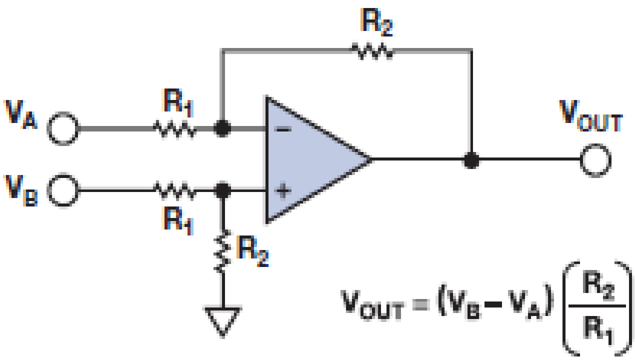

Figure 3. Difference Amplifier

To reduce noise, the output of amplification will be fed to Schmidt trigger inverter which is known better for slow changing signals, or noisy signals. Then the signal undergoes latching process to be completed as a trigger. Figure 4 illustrates amplification results of the developed prototype.

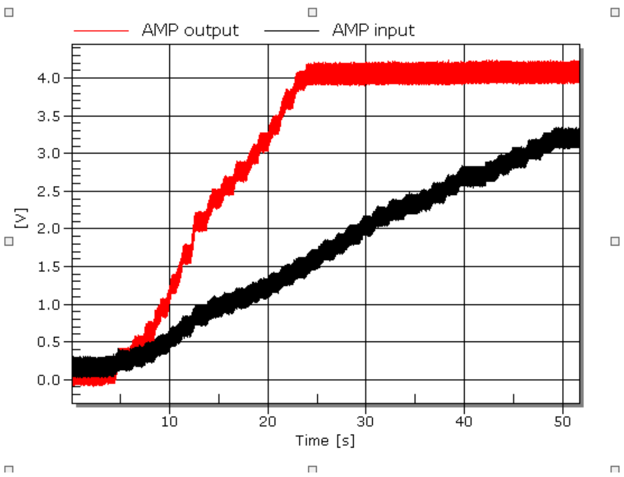

Figure 4. Amplification results

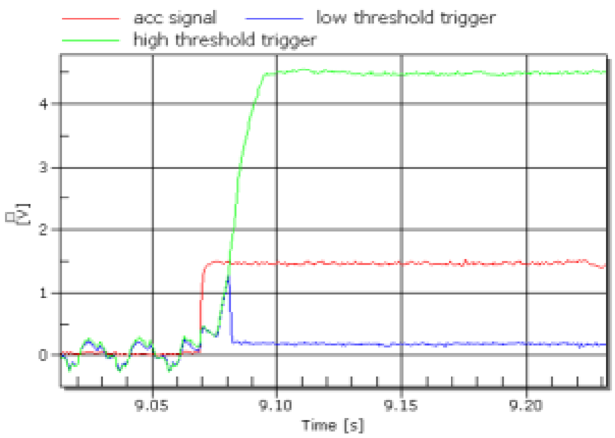

Figure 5. False Trigger during Start up

To solve initial uncertainties and resulting false trigger generation during power up the module includes racing problem of flip-flops, the following preventive measures are taken.

(1) Use master-slave configuration for flip-flops. Slave flip-flops handle actual triggers while master flip-flop handles initialization and preparation for triggers.

(2) Use timer to reset flip-flops after power up the module.

(3) Output triggers are controlled by an octal buffer. Octal buffer allows data output only after the above pulse.

Summering the above steps we can form a timer based sequence that consist of a pulse to set master flip-flop, reset slave flip-flops and enable octal buffer for outputs.

III. LINEAR FREE FALL TEST

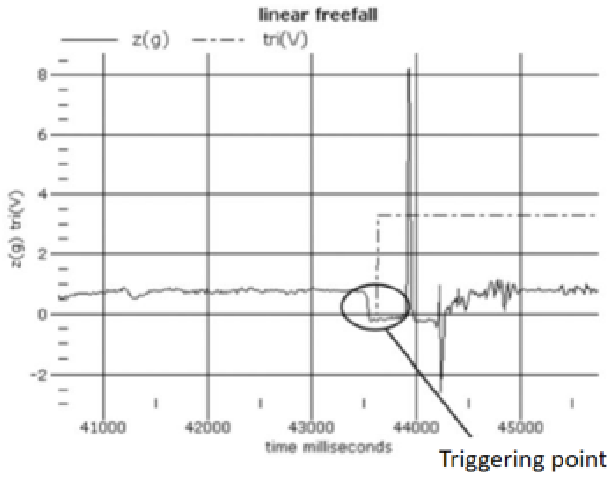

Figure 7. trigger generated during linear free fall

Figure 7 illustrates the trigger generation during linear free fall. As expected the trigger (in dotted line) is generated at the start of fall within a very short time.

IV. ROTATIONAL FREE FALL TEST

The following figure 8 illustrates the validation test results of the developed module during rotational fall. Dotted line illustrates the trigger obtained.

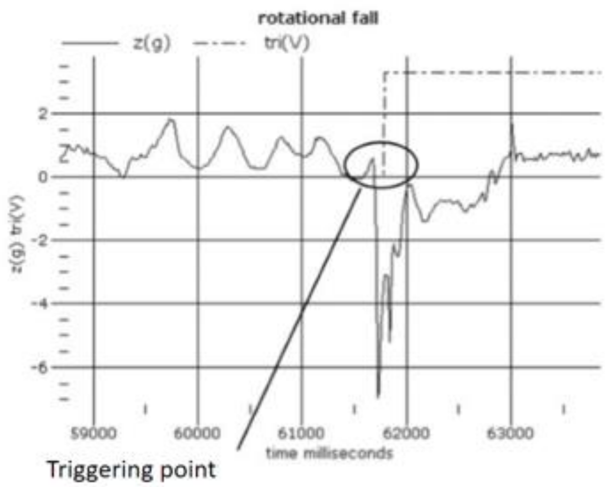

Figure 8. Rotational free fall test

V. CONCLUSIONS

From linear free fall test and rotational free fall test it can be stated that expected triggers for z axis signal are generated and latched properly. The proposed analog design can be considered to be valid as a primary trigger generation module for in-flight emergency system.

As a contribution to further development on this topic, possible comparative technical argument on this design is mentioned as follows.

In this design the trigger values obtained are in considerable accuracy. For better visibility test results are presented in g values. One may argue that dependency on single reading may generate false triggers. Practically no such errors occurred so far with the analog accelerometers used in experiments except for S-Factor base detection.

If in case of errors the detection scheme could be altered by adding a timer based second layer of reading to confirm a generated trigger. Many digital systems use this confirmation method.

From test data, especially from detailed signals illustrated in figure7 and figure 8, object signal consist of spikes rather than continuous signal. It is doubtful that we could obtain a finite second value of reading during the fall despite the presence of multiple spikes.

Cost of adding a second layer is a time consumption, i.e. trade off on module response time. If the altitude of fall is low, straight forward question is the availability of total time before the impact. Therefore the method of single reading with carefully selected threshold values are better suited here. It should be mentioned that UAV flight is susceptible to vibrations. This is exactly why the algorithm has to be expanded.

As a further development for this research, a fully functional robust free fall detection device with novel detection algorithm is proposed, developed and patented as mentioned in [9].

VI. ACKNOWLEDGEMENTS

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