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CAMERA GIMBAL CONTROL SYSTEM FOR UNMANNED PLATFORMS

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Abstract: *This paper gives an overview of a gyro-stabilized motion control system for camera gimbals designed for unmanned systems. The original mechanism was initially developed for medium sized remotely piloted helicopters, but the system has now gone through a 2nd development stage and therefore can be implemented into both smaller and larger applications ranging from miniature UAV systems to large scale observation platforms. The functioning prototype gimbal mehcanism has a 3 axis design driven by gearhead DC motors with incremental encoder feedback and AHRS unit for angular movement corrections.*
Key words: UAV, camera gimbal, IMU, AHRS, remotely piloted helicopter, motion control system.

1. INTRODUCTION

The aim of this project was to develop a gyro-stabilized camera control system that could be adapted into various types of camera stabilization mechanism of unmanned aerial vehicles. The reasearch and development in the field of mechanical and electrical engineering have led to a rapid upgrade in the market of available system components, which can be used as key elements in this type of electro-mechanical system. Some of the notable components that have gone through significant improvement processes during the recent past are:

- Attitude and Heading Reference Systems (AHRS)
- DC gearhed motors with integrated incremental encoders
- Modular ultra high resolution miniature incremental encoders
- Fast and capable microprocessor systems and single board computers (ARM technology for example)

Other highly important factors, which help to design and manufcature a system of moderate complicity, are 3D CAD programs like Solid Edge with Syncronous Tehcnology and availability of instant CNC machining to manufacture the prototype of the designed system. Mastering all the necessary fields from component selection to 3D modelling and CAM programs help to reduce the overall time from the beginning of the project to the first prototype. The development of this system has followed the path illustrated in Fig. 1.

2. PROTOTYPE

The first objective was to design a test system with 3-degrees of freedom, where all DOF's are rotations in a coordinate system X-Y-Z connected with an aerial platform, which itself is related to ground (Fig. 2). The Pan (Z-axis) must have limitless movement in order to have the constant ability to be directed onto the designated object no matter the yaw angle

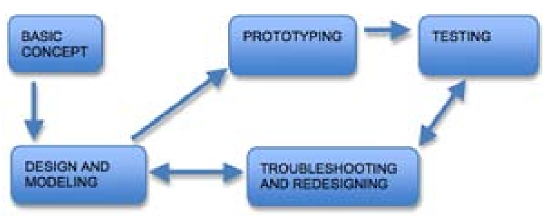

Fig. 1. Design process

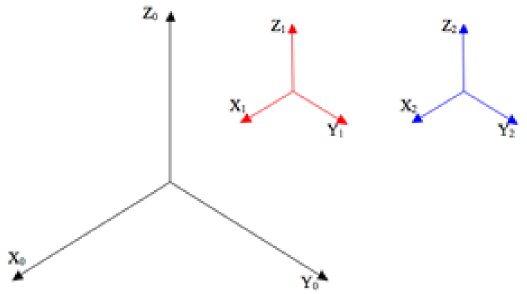

Fig. 3. Coordinate system 0 - ground, 1 - air vehicle, 2 - camera gimbal

of the platform. Tilt and roll axes (Y and X) rotational movement range depends higly on the pitch and roll movements of the aerial vehicle and also the task of the gimbal. For example if a gimbal for a photocamera had a roll axis movement range of ±90 degrees and an additional 10 degrees of stabilization overlay, it could easily be used to take Portrait and Landscape pictures during the same flight without the need to mechanically reposition the camera.

An important point was to keep in mind that the system must have the ability to be implemented in mechanisms of very different size and purpose. No matter if it is a 1, 2 or 3 axis mechanism, miniature, medium or large sized, for stabilizing a video- or photocamera or other sensorics like spectrometers – the same core system can be used and reconfigured with ease.

All things considered, the most suitable flying platform for a first prototype was a remotely piloted helicopter as it can hover and move very slowly and thus makes an ideal solution to develop the camera gimbal system and tune its parameters. Hereby a 3 axis mechanism for a Canon DSLR camera was decided to be built as the prototype mechanism.

The gimbal should actively compensate the rotational movements of the helicopter it is mounted on. Two of the main aspects in all motion control systems with similar tasks are position feedback and position reference data. Feedback tells us where the mechanism is, reference tells us where the mechanism has to be. The resolution of the feedback device along with the update frequency and accuracy of the reference unit are essential figures if a smooth and precise system is conseptualized. The kinematics scheme, mechanical properties and quality of the components and assembly determine the final quality of the system.

2.1 Kinematics scheme

The 3 axes of the prototype system compensate all the angular movements of the hull it is attached to and the general principle of the axes arrangement assure it is able to avoid the *gimbal lock* state during its normal operation. The configuration - *pan* over *tilt* over *roll* (Fig. 3) - allows up to 90 degrees of roll or pitch movement by the aircraft before a *gimbal lock* occurs, which of course is highly unlike to ever happen.

2.2 Rotational movement feedback

A simple camera control mechanism (camera gimbal) has 2 degrees of freedom – pan and tilt, that are driven by actuators which, incase of manual control, do not necessarily need to have any sorts of feedback (e.g. security camera gimbal in a supermarket). Now if we want precise information regarding the cameras rotational movement, we must have either analog or digital feedback units installed, that detect rotational movement of the gimbals axis. Analog rotational movement detectors are called potentiometers, they output voltage, digital ones are called

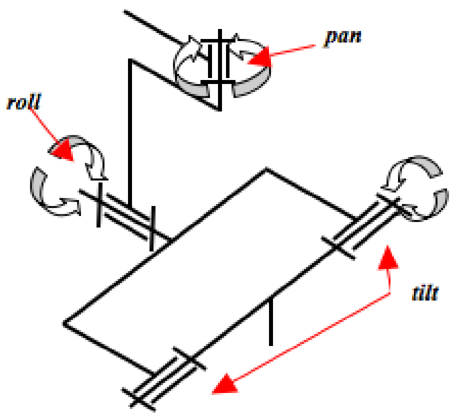

Fig. 2. Kinematics scheme showing 3 revolute joints

rotational encoders, which output binary code. Potentiometers may cause drift as they are quite temperature sensitive and they normally have rotational limits and therefore not being able to provide continuous rotation in certain needed situations - pan axis for example.

Rotational encoders, on the other hand, have no drift and no limits regarding rotational movement. They lack drift as the output is a digital signal, which is in direct line relationship with the encoders resolution and the movement angle of the encoders axis.

Rotational encoders output can either be absolute or incremental, with absolute having a unique binary code for every position and thus the number of contact wires increases in conjunction with the resolution. Incremental encoders on the opposite have usually only 2 channels and 2 signal wires that give out readings regarding the direction and increments of the rotational movement.

Both encoder types come in various sizes and configurations and both have advantages and disadvantages in different fields of usage. In small and miniature camera gimbal mechanism however, a incremental encoder type has better features than absolute encoder especially by having a significantly better size to resolution ratio and this is the main reason why incremental encoders were chosen to be utilized in the described camera control system.

2.3 Initial absolute positioning

The described system can use different types of incremental encoders – for example modular encoders that may be installed to the gimbals output axis in various configurations, or integrated encoders, which already are assembled into the end shaft of a planetary gearhead motor. In most cases, incremental encoders

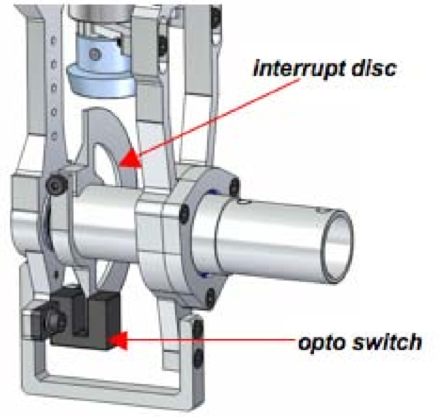

Fig. 4. Opto switch and interrupt disc for axis absolute positioning

need to be zeroed, or in other words, they need to know their *home position* about what the relative position feedback is given to.

Using an optical switch and an interrupt disc (Fig. 4), which determines the state of the axis right after the power up of the system, solves the homing of each individual axis. The optical switch has a binary output, so if the interrupt discs separator line is mechanically aligned to 0 degrees, the direction the axis needs to be moved after power up is known and when the optical switch registers a binary signal transition, the home position is reached and the incremental encoders offset will be zeroed.

2.4 Positional reference system

Another highly important device is an *Attitude and Heading Reference System* or simply AHRS, which provides data about the attitude change and the heading of a rigid system. The accuracy and update rate of the unit determine how fast and precise is the registering of change in attitude and heading and how often can correctional data be sent from the main controller to the motor controllers. The most suitable AHRS for this project was a SBG Systems IG-500 A that has 100 Hz update rate and +/-1 degree error margin.

Apart from the mechanical stiffness of the mechanism, the feedback resolution and precision of the AHRS are the main parameters that determine the possible accuracy of the completed camera gimbal.

2.5 Prototype mechanism

After the basic calculations for moment of inertia of each axis and motor selection, the gimbal was modeled in Solid Edge ST (Fig. 5).

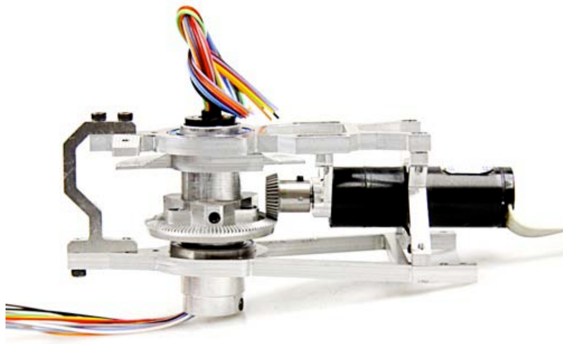

Fig. 5. Testing mechanism for integrating a slip-ring module

The gimbal consists of three sub-assemblies that divide into smaller segments. The whole device is constructed to be very modular and easily reconfigurable incase a component needs to be replaced. A variety of different DC motors, encoders and transmissions were tested before an acceptable solution was reached and testing could start.

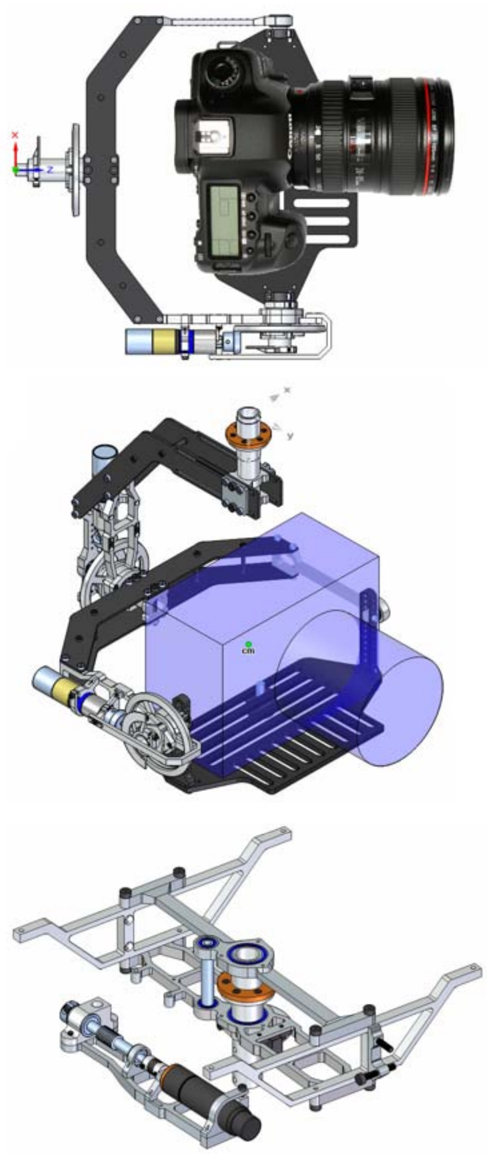

Fig. 6. Assemblies of the prototype gimbal

Roll and tilt axis use the same motors and bevel gear transmissions to assure the unified movements of the tilting axes. Pan axis has a worm gear transmission and a high-speed motor. The self-braking worm gear takes the load coming from sudden pan axis decelerations and prevents the transmission to break incase of an under slung configuration on a RC helicopter.

As the pan axis has limitless movement capability, it is equipped with a slip-ring (Fig. 6) for the power and signal contacts in roll and tilt sub-assemblies and all the control signals [4].

2.6 Vibration

The helicopter has 4 main vibration sources: main rotor, tail rotor, electric motor and transmissions. The motor, tail rotor and transmissions have relatively low vibrations compared to vibrations coming from the main rotor and their effect to the cameras sensor is minimal.

The only considerable vibration source is the main rotor which spins about 1500…2000 rpm having a frequency of 25…33.3 Hz. It is very hard to measure the vibration and take every different situation into account – mass of the camera, angle of the main blades etc. and the fastest way to find a solution for vibration dampening is by trial and error.

There are a few good sources for information about wire rope isolators [1], [2]. For the prototype a custom wire rope isolator with exchangeable and extendable wire rope was designed.

2.7 Motor controllers

Combining the DC motors, encoders and opto switches was another major task [3]. In order to assure that different sized motors with varying input voltage and power could be used, an all-in-one motor controller was designed. The controller has a Silabs 8051 series processor type F310 and a BD6231F H-bridge, which can drive 6-24 V motors and give output current up to 1 A. The principle of the motor controller is shown on Fig. 7. It has 2 separate communications protocols for added functionality – UART and I^2C. The same motor controller can be used with a DC planetary gearhead motor equipped with an integrated encoder, or a suitable DC motor and an external modular encoder (Figs. 8-9), depending on the configuration of the system. Different motors can be used as long as the supply voltage and current consumption are within limits.

2.8 Main Controller

All of the above must be joined with a main controller unit. The main controller has to be able to perform matrix

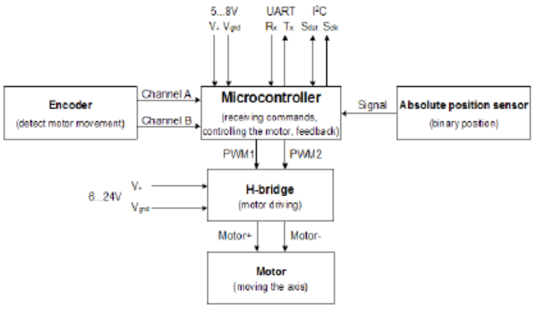

Fig. 9. Block diagram of motor controller

calculations, read the AHRS output and

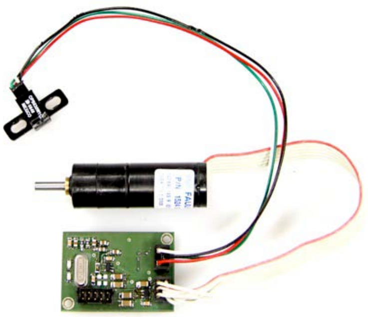

Fig. 7. Motor controller with an integrated encoder/motor

Fig. 8. Motor controller with modular encoder

communicate with a data modem and motor controllers. In order to do that 2 UART and I^2C protocols was needed. There were 2 suitable single board computers – Beagle Board and Gumstix Overo. Both are based on ARM Cortex A8 processors, which have excellent efficiency and are widely used in many multimedia applications like Smart-phones, GPS devices and PDA’s. Gumstix has extension options for WiFi and Bluetooth and smaller overall dimensions.

3. FUTURE DEVELOPMENTS

The prototype for the remotely piloted helicopter has gone through extensive testing and some major changes to improve the performance of the system. One notable change is the replacement of the worm gear pan axis with a bevel gear design identical to Tilt and Roll axes.

The system has also been used in smaller test platforms for airplanes. A 2-axis miniature camera gimbal, 1 axis photo camera stabilization mechanism and a mechanism for targeting a directional antenna has been tested with the same system. Designing a medium sized duo-camera gimbal is in progress. All is done with the same system by only changing the axis layouts, selecting appropriate motors/encoders and setting up the system with suitable parameters.

4. CONCLUSION

As a conclusion, a multi-axis motion control system for different purposes was developed (Fig. 10). The described system has a very flexible configuration option meaning that it can be used in many mechanisms that need motion control. Apart from its primary purpose of controlling camera gimbals, it can be used for leveling or moving sensors like spectrometers, laser rangefinders, directional antennas etc.

Further research and development must be done to work out the best methodology for setting the correct operating parameters of the main controller and DC motor controllers via a user-friendly configutation wizard and to design more stabilization platforms for testing the different settings.

The final outcome of this research project is a higly adaptable, fully configurable motion control system for a wide range of sensors that can be used in general purposes like aerial photo- and videography or narrow fields like power line inspections, heightmap generation for mining pit examinations, forest data cathering with spectrometers, post forest fire inspection with thermal cameras, military and police surveillance etc.

5. ACKNOWLEDGMENTS

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Fig. 10. Remotely piloted platform with 3-axis prototype gimbal