Proceedings of the
2007 IEEE Intelligent Vehicles Symposium
Istanbul, Turkey, June 13-15, 2007

Aricopter : Aerobotic Platform for Advances in Flight, Vision Controls and Distributed Autonomy

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Abstract— **Aricopter is a COTS micro-helicopter heavily modified for research on embedded flight and vision controls, and distributed autonomy. In this work, we present an overview of the exciting development process of the flight hardware, the micro-avionics system, and the off-board vision implementations.**

KEYWORDS: micro helicopter, ground robot, flight controls, vision controls, distributed autonomy, command and control, unmanned air vehicles

I. INTRODUCTION

Experimental flight platforms, such as Aricopter, provide a unique opportunity to prototype and demonstrate novel concepts in a wide range of topics covering agile maneuvering[2], advanced flight controls[1], [4], active vision sensing and fleet autonomy[3]. Furthermore, such platforms are very suitable for students to obtain and develop hands-on skills with minimal risk and cost trade-offs.

Towards this end, we have developed an experimental micro-helicopter and supporting ground systems. Aricopter equipped with sensors and on-board computing devices, provides the necessary infrastructure to support advanced research on embedded flight, vision based control and distributed autonomy. In this work, we give a brief overview of the development process involved with this experimental flight platform. The paper is structured as follows :

In Section II, we present the physical configuration of Aricopter, as shown in Fig. 1, and the mechanical modifications that was completed to support autonomous flight. In addition, lab and field support systems is introduced. These support systems include a ground test vehicle (a heavily modified 1/6 scale Hummer) that is used for extensive electronic system tests.

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Fig. 1. Aricopter with avionics pod replica and camera at early flights.

Section III provides a brief overview of the core micro-avionics system [1], flight controls software implementations and the results from field and hardware-in-the-loop tests. Also, the ground station for the human operator interface is presented. Section IV covers the results from the off-board vision processing software and the new on-board vision system that is being developed. Some earlier results can be in seen at Figs. 2,3.

II. FLIGHT AND GROUND VEHICLES

A. Aricopter

Aricopter's base structure is a COTS benzine helicopter manufactured by German model helicopter manufacturer Vario. The Benzin trainer model of Vario is selected to be used as the flying platform, among the rivals; Century Heli's "Preadator Gasser" and Bergen R/C's "Industrial Twin" because of Vario's advantages on price, structural strength and lifting capacity. Table I summarizes the operational characteristics of our flight platform. The main features and selections that we made for our flight vehicle can be structured under mechanical and remote control components.

[1]We refer the reader to [5] for an in-depth description of the micro-avionics system.

Fig. 2. Aerial wide-area video capture from 50m.

Fig. 3. Aerial local-area video capture in the parking lot.

OPERATIONAL CHARAC.	VALUE
Empty weight	$7,35$ kg
Operational Weight	$10,1$ kg
Maximum take off weight	~ 12 kg
Operational speed	~ 45 km/h
Maximum speed	~ 95 km/h
Range (MTOW $\%75$)	~ 13 km
Endurance (MTOW $\%75$)	~ 18 min

TABLE I

VARIO BENZIN TRAINER OPERATIONAL CHARACTERISTICS

- *Fuselage-Frame:* Vario benzin trainer has metal fuselage frame. The fuselage frame consists of three main parts; right side, left side and the bottom side. Engine is mainly mounted to the bottom side of the fuselage. All the servos except the rudder servo are attached to the right and left side of the airframe.

- *Rotor/swashplate/tailrotor:* Vario offers symmetrical and semi symmetrical-reflexed profiled main rotor blades. Symmetrical main rotor blades are generally used for aerobatic flight. They are not efficient and do provide more load to the engine in heavy lifting operations. Therefore, as suggested by Vario company, 800mm length semi symmetrical reflexed main rotor blades were chosen for test flights since they have less moment coefficient. As a result of that, the reflexed blades generates less torque to the blade grips in comparison with the torque generated by symmetrical blades (thus avoiding high mechanical load and material fatigue). We use the original tail rotor blades coming with the Vario benzin trainer kit. The tail rotor blades have symmetrical airfoil and each have a length of 120mm. The total diameter of tail rotor including the length of tail rotor hub is 312mm. The tail rotor blades generate enough counter force so that they can compensate the torque of main rotor in the heavy loading applications. The swashplate on the helicopter is 90 degree CCPM (Cyclic Collective Pitch Mixing) allowing four servos to be used for every type of motion of the swashplate. The general specifications of the Vario Benzin Trainer helicopter is summarized under Table II.

PHYSICAL CHARACTERISTICS	VALUE
Main rotor diameter	1780 mm
Tail rotor diameter	312 mm
Fuel Tank capacity	500 cc
Engine displacement	26 cc
Engine Horsepower	N/A
Main rotor gear ratio	9.1 : 1

TABLE II

VARIO BENZIN TRAINER SPECIFICATIONS

- *Remote control system / Receiver/ Servos*: For manual control, we use Futaba's 9 CAP transmitter. 9CAP transmitter has ability of sending nine different commands to the helicopter, the control switch circuit (which allow transition to and from piloted flight to autonomous mode) and the external pan-tilt camera. 9 CAP is a computerized transmitter and has several features that allows us to store the models of many different vehicles and create custom channel mixes. To receive the signals coming from the transmitter, we used Futaba's R149DP, nine channel receiver with PCM (Pulse Code Modulation) modulation and thus reduce the interference probability. Different types of Futaba servo motors has been used in the helicopter as actuator motors; S9254 for yaw control, S9451 for cyclic and collective controls and S9202 for throttle control.

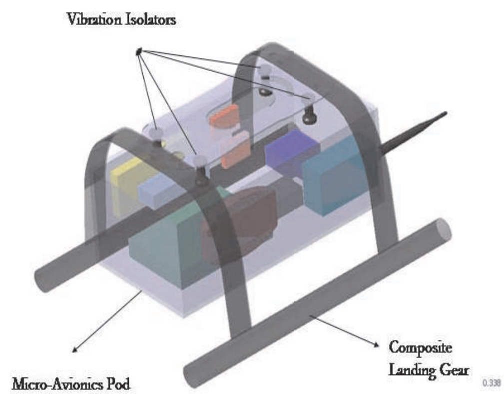

Fig. 4. Vario modifications : new landing gear, micro-avionics pod and the vibration isolators.

- *Batteries:* There are two types of batteries on the flying platform. Receiver battery supplies adequate energy for all the servos and the gyro on the helicopter, and receiver battery includes four 2000 mAh Nickel Cadmium (Ni-Cd) batteries which produce 1.2 Volts per cell. As the main power source, 3000 mAh 10 cell Nickel Metal Hydride (Ni-Mh) battery package producing 12V potential totally, is used for micro-avionic box.

- *Engine:*The G26 model by Zenoah4 that came with the helicopter is a 26 cc, two-stroke gasoline engine which pre-installed clutch and cooling fan. It can easily be started with the pull start system. In flight, G26 runs between 12K-13K rpm. To reduce RPM coming from engine, two staged reduction is used.

B. Vario Modifications

For to support autonomous flights, the following modification was done on the system :

- *Landing gear:* The new landing gear as shown in Fig. 4 was one of the main modifications on the helicopter introduced to accommodate the size and the weight of the micro-avionics box. To build the landing gear, we used unidirectional carbon fiber with foam core.

- *Avio-Pod placement:* The avionics box is placed under the fuselage of the helicopter and between the landing gear skids. The two critical points considered for the box placement was a) to coincide the rotor shaft with the center of gravity of the helicopter and the box, and b)to place the IMU unit as close as to the center of gravity. To avoid vibration due to moving parts on the helicopter like engine piston, main and tail rotors, we tested several caoutchouc vibration isolators to select most suitable one for our vibration frequency interval.

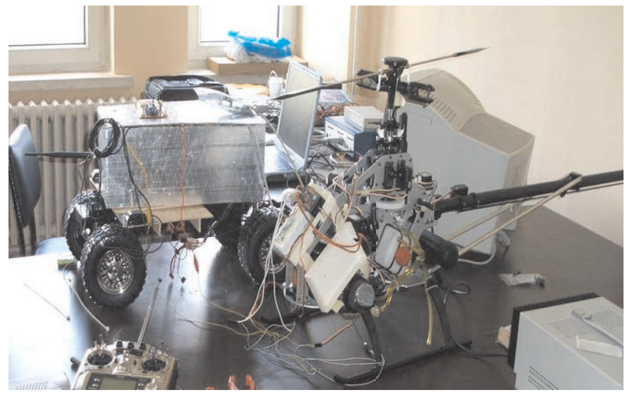

Fig. 5. Hummy with Avio-Pod connected to Vario-Acrobatic before a HIL test.

C. Hummy

Hummy (shown in Fig. 5) is a ground vehicle which is used for testing the basic functionality of the avionics system. It is a 1/6 scale model of Hummer and it is manufactured by Nikko. We have made some modifications to convert the vehicle to a form that is more suitable for our applications. First modification was made on the radio gear. We replaced the original radio gear with our Futaba radio gear including four channel FM receiver and a Futaba S3001 ball bearing servo. In addition to this, we had to separate the Electronic Speed Control (ESC) to drive the motor of Hummy. We used 10 Ampere Great Planes electronic speed control unit. This ESC system was then used for controlling the DC motor originally placed by Nikko. Note that, both the steering and the DC motor are driven by PWM based signals which are compatible with the PWM signals provided by the receiver. Second modification was to the servo linkage. We adjusted the length of the pushrods and produced a new servo horn by using an in-house "Rapid Prototyping Machine" which is able to print three dimensional objects.

D. Physical Characteristic Determination for Mathematical Modeling

To develop the basic mathematical model and to identify the key inertia properties, we have developed a Bifilar torsion pendulum. The experimental set-up is shown in Fig. 6. The moment of inertias of the helicopter is determined by measuring the oscillation period about the center of mass of the whole system including the pendulum and the helicopter.

In addition, to limit the degradations in stability and control, the center of mass of the helicopter needs to be placed almost exactly on the axis of the main rotor shaft. To ensure this, helicopter is hanged from its main rotor shaft and the component placement has been done such that the horizontal axis of the helicopter is parallel to the ground.

Fig. 6. Moment of Inertia Test System.

III. Micro-avionics and Flight Controls

Our micro-avionics core design is structured around the Phytec Motorola MPC555 processor and the development board. One of the unique enabling features of MPC555 is that the Matlab/Real-Time Workshop allows embedded targeting of algorithms for rapid prototyping. In addition, the availability of drivers for serial and CAN Bus communications, MIOS functionality provides relief from coding of the physical drivers. However, its limited TPU usage capability and the necessary data-parse coding of each different type of sensor required a considerable amount of customization for our purposes. Towards this end, we have developed a Simulink block library and necessary drivers for each different sensor employed within the core micro-avionics design[5].

The core design's basic sensor suite consists of Garmin 15H GPS receiver, 3 axis accelerometer/gyro Crista IMU, Honeywell HBP altimer and Honeywell HMR digital compass. This system provides us with real-time inertial position, orientation and their rate information for control and navigation implementations. For autonomous operations, we have developed a multi-channel autopilot/operator switch which allows us to transfer pilot control to the avionics system (and vice versa) over each of the vehicle's controls. In addition,this core design is extended to a multi-processor architecture (with the inclusion of an ARM 7 based processor) structured around CAN Bus. Extensive treatment of the avionics development process and the in-house developed algorithms and components can be found in [5].

Basic functionality of the avionics system has been successfully tested on the Hummy through field tests (shown in Fig. 7). In addition, the controller software performance in real-time is tested using a hardware-in-the-loop setup connected to our lab Vario Acrobatic implementation helicopter.

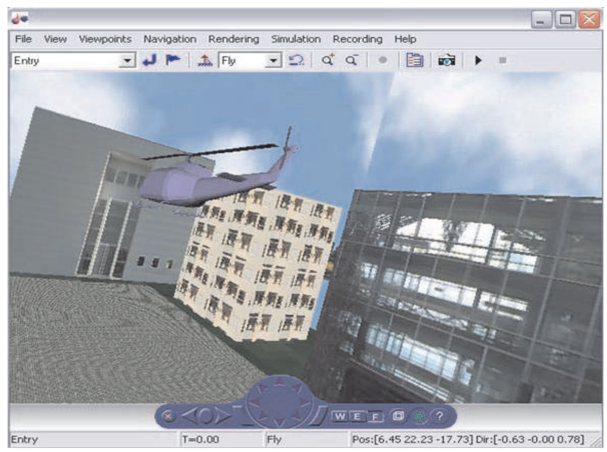

Fig. 9. Virtual Reality implementation from the HIL Tests.

The hardware-in-the-loop setup, seen in Fig. 8, includes three different computer systems. The first computer system is the MPC555 embedded computer which runs the main control algorithm and all other related operational algorithms. This computer system includes both the hardware components, and the controller hardware and software sections. The controller hardware runs the software needed for fully-autonomous operation of the helicopter communicating with the ground station and sensory systems and controlling the servo actuators. It also executes the control algorithm for autonomous control of the vehicle which is given in Fig. 10. The control algorithm outputs are used for controlling the servos on the model helicopter and are transmitted to the xPC Target Box via a CAN connection. Another computer in the system is the xPC Target Box which is used for simulation of the helicopter dynamics. The

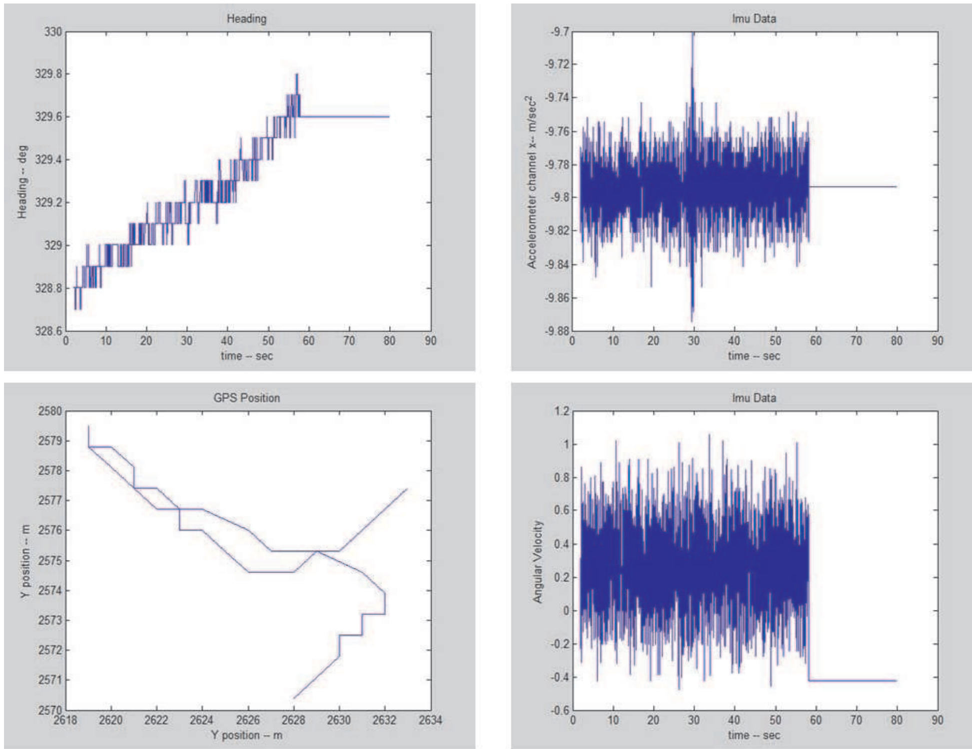

Fig. 7. Hummy test data from field tests : GPS position, Magnetometer heading and, acceleration and angular velocity data from the IMU.

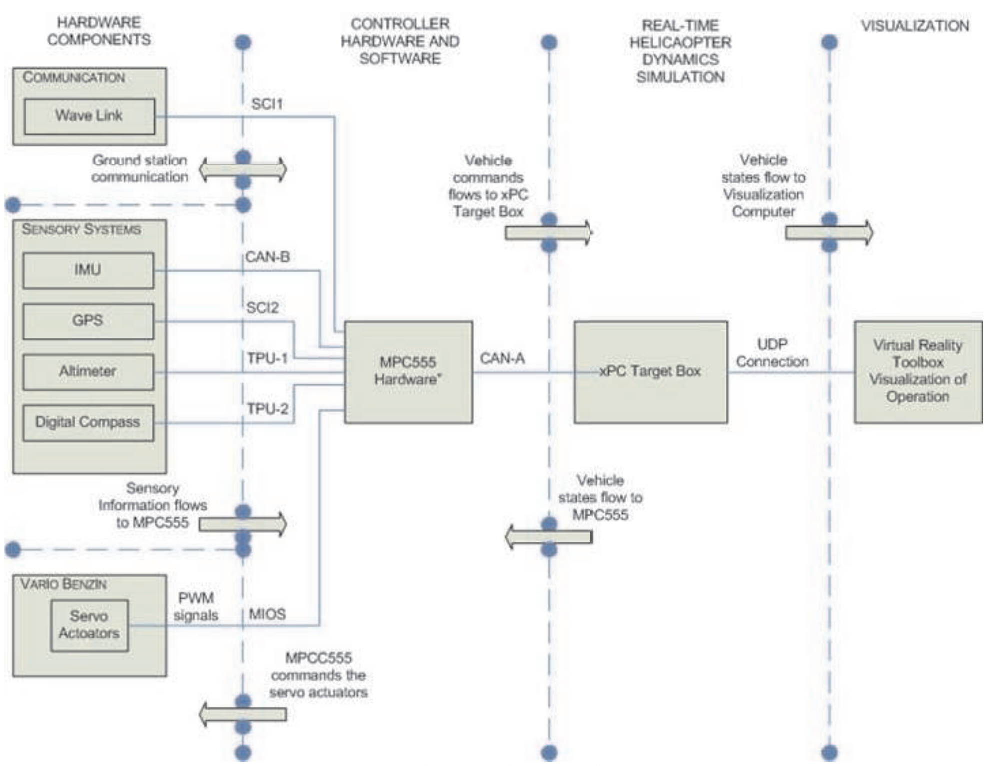

Fig. 8. Hardware-in-the-loop setup showing the micro-avionics architecture and the test computers.

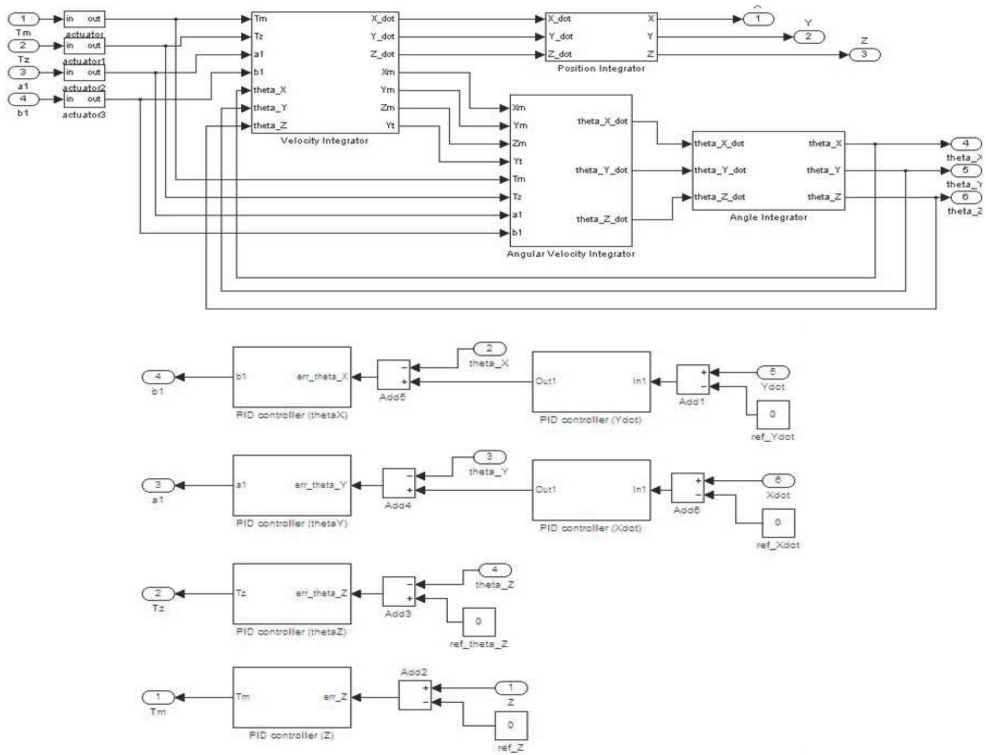

Fig. 10. Control implementation in the micro-avionics system. The dynamics is simulated in xPC target.The controller is embedded in the micro-avionics MPC555 processor.

Fig. 11. Ground Station Interface For Aricopter.

final computer system is for visualization. This computer runs Virtual Reality Toolbox (as illustrated in Fig. 9) of Matlab together with the UDP communication interface of xPC Target.

A. Ground Station - Operator Interface

We have used C# and the .NET framework for rapid development of the ground station software. Important displays were made more prominent to enable determination of the general state of the vehicle by a quick glance. The altitude, main rotor speed, air speed and heading as well as the general attitude can easily be observed from the various displays. The 3D pane used for attitude visualization is based on OpenGL for cross-platform compatibility.

The communication between the flight, ground platforms and the ground station is via a frequency hopping spread spectrum modem operating at 2.4 GHz. The receiver sensitivity of the modem is -101dBm, allowing a line of sight range of 2 km with the integrated antenna. The modem is interfaced via the RS-232 serial port and operates at 19200 Baud. Multiple modems can be combined for communication between multiple vehicles and the ground station.

The communication packets from the autonomous vehicle to the ground contains GPS coordinates of the vehicle, heading, pitch and roll angles, pressure, three components of the velocity vector and three components of the acceleration vector. It's broadcasted at 2Hz from the vehicle. The packet is built at the receiving station as data comes in and is discarded if corrupted or incomplete. It is checked to see if the ID matches the ID of the currently displayed vehicle, and then processed for the display of the position and state parameters.

The command and control from the ground station to the vehicles is via waypoints which can be added either by right clicking the desired place on the map and choosing the appropriate command from the context menu, or by entering the GPS coordinates manually from the same context menu. They can later be moved or deleted. In order get a single computer to act as a ground station for multiple vehicles, it's possible to select between different vehicle IDs and display the state of the selected vehicle. The ground station interface screen can be seen in Fig. 11.

IV. Vision Controls

One of our primary goals in this project, is to effectively use vision to guide ground robots, aerial robots, and also groups consisting of both type of vehicles. The most important capability of the vision system is to capture images and to identify features in these images. This information then will be used to locate ground objects, landing sites, relative position of objects, and also to track other vehicles. Vehicle localization problem will be investigated with vision-based Simultaneously Localization and Mapping (SLAM) using monocular cameras, omni-directional cameras.

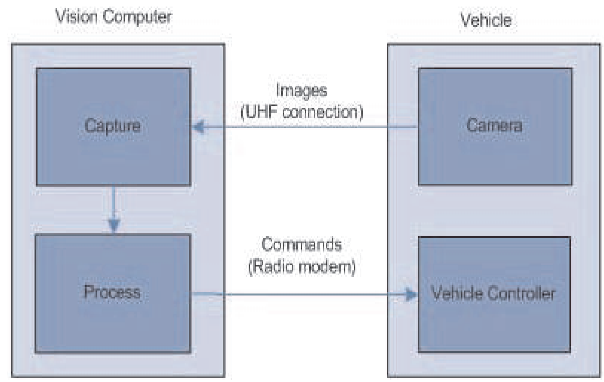

Fig. 15. Off-board vision system.

An off-board vision system has been developed for the initial tests. First tests involved frame grabbing from various devices and processing them with MATLAB, MIL (Matrox Imaging Library) and custom codes written in C. Camera on the ground or aerial robot transfers images with wireless transmitter to the off-board vision computer (shown in Fig. 15). The processing takes place on the off-board computer. The desktop system used in these studies consists of a standard security camera and a Matrox Meteor II / Standard frame grabber which has one s-video input. Camera is connected to the frame grabber through a radio transmitter. Refer to Figs. 12, 13, 14 for initial tests involving standard edge and corner detection algorithms. Our preliminary analysis showed that the off-board image processing greatly reduced the autonomy and the effective range of the system.

A. On-board Vision Computer Design

The vision system under development will replace the off-board vision system. The vision system that is being built is a PC-104 stack, which consists of a T886ULP8-800/512 low power CPU board, 2GB microdrive, 2 GB solid state disc, a PCMCIA wireless network adapter, a dual channel CAN bus board, HESC104 power supply and three-input firewire PC-104 frame grabber for cameras integrated into system as shown in Fig. 16.

Although most of our earlier work is done using custom codes or MATLAB, from the three initial alternatives, Matrox Imaging Library (MIL) is the most suitable solution for on-board processing. MIL is an easy

Fig. 12. Original photograph of the I.T.U. Aeronautics & Astronautics Building captured by the micro-helicopter.

Fig. 13. Corner detection using the corner detection library.

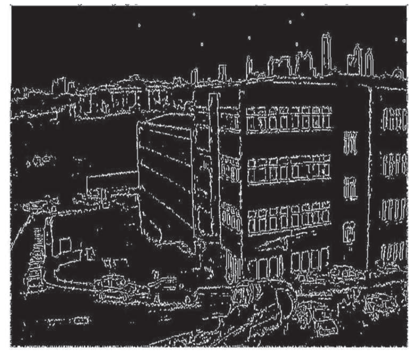

Fig. 14. Edge detection using the edge detection library.

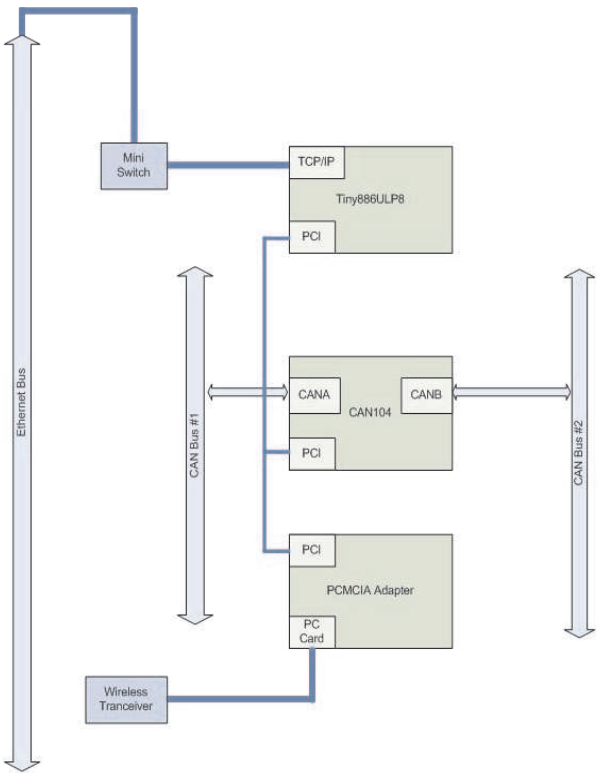

Fig. 16. The new on-board vision architecture.

to use library for many image processing applications (blob analysis, pattern recognition etc.) so, focusing on more challenging points becomes possible. However MIL doesn't support stereo vision applications therefore stereovision part of the project will be implemented totally with custom C codes integrated with MIL.

V. Conclusions and Future Directions

Our current research focuses on designing coordination algorithms and vision controls that allow interoperation of the ground and the flight vehicles in urban environments.

VI. ACKNOWLEDGMENTS

The authors gratefully acknowledge the contribution of Ayse Tekes, Murat Demirci and Serdar Ozturk for their work at the beginning phase of the project. This work is partially supported by DPT HAGU program administered by the ITU ROTAM.

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