# Design and Implementation of Vision-based Structural Safety Inspection System using Small Unmanned Aircraft

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***Abstract*** **—Safety inspection for high-rise structures should be done regularly for follow-up test. However, as it is very dangerous job and direct manual examination takes a lot of time and money, its correct diagnosis is difficult. In this paper, computer vision-based structural safety inspection system is proposed to be designed. The proposed system is an image recognition monitoring system through wireless transmission of sensor data by loading multiple sensors for facility monitoring in UAV platform. The system loads various sensors such as temperature sensor, humidity sensor, smoke sensor, illuminance sensor, CO2 sensor, ultrasonic sensor, and infrared thermal imaging sensor and can achieve stability inspection. So, It can reduce inspection time and building's maintenance cost**

***Keyword*** **—small unmanned aircraft, Multi -Sensor, Monitoring facilities, Safety inspection, Image Processing, Sensor Fusion, openAPI**

## I. INTRODUCTION

In domestic construction industry field, as number of facility that was constructed more than 20 years ago is increased, accident by facility damage and collapse is taken place frequently and its occurrence frequency is showing a tendency of being increased due to facility deterioration and negligence of safety check-up. Therefore, sustained safety inspection and management are required but inspection of high-rise buildings with its height over 10-100m by inspectors with directly carrying inspection equipment is too dangerous and requires lots of time and cost.

Therefore, in order to perform integrated inspection of several structures of which access of inspector is limited and confirm damage status of structure to be inspected based on time difference by each season and day, inspection method using unmanned aerial vehicle (UAV) that is effective for shortening inspection time and reducing maintenance cost is urgently required. In this study, computer vision-based structural safety inspection system is proposed to be designed

Proposed system is an image recognition monitoring system through wireless transmission of sensor data by loading multiple sensors for facility monitoring in UAV platform.

This system has an advantage of being able to perform more accurate, precise inspection and diagnosis through image processing on the ground by identifying problems after approaching high-rise structures through remote control using UAV equipped with video camera.

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## II. RELEVANT STUDY

### A. Definition of UAV and its Utilization Field

UAV is a small aircraft on which pilot is not boarded and it has a separate remote control operator on the ground and it is also called as drone meaning that it looks like a buzzing bee. In the past, it was mainly used for reconnaissance target or military purpose but recently, its usage has been diversified including private and research survey purpose. [1]

At present, in order to apply UAV control technology to diversified fields including documentary shooting or pesticide spraying, diversified researches are under progress [2] and in case of image analysis level, technology development for substituting physical sensor including fire watch-out, behavioral watch-out has been advanced to a considerable level. [3]

In overseas case, mainly Japan, Germany and U.K. show unusual concern over maintenance and safety inspection of structures and Fraunhofer ISE, Germany and Cyberhawk, U.K. have developed and commercialized UAV for safety control of wind power structures.

Recently, DHL, Germany started parcel delivery using drone and Amazon and Google, USA are preparing unmanned home delivery service.

### B. Computer Vision Technology and Algorithm

In order to extract information contained in image by

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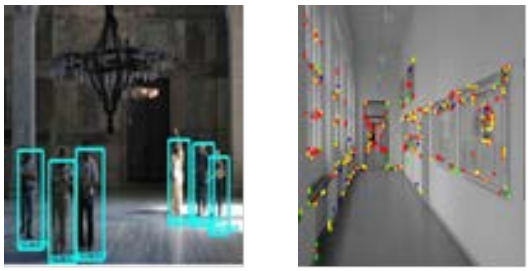
analyzing it photographed from camera mounted in UAV, computer vision technology is required. Computer vision technology is widely applied to diversified applications including text recognition, biometrics, positioning, 3D image restoration, augumented reality [4]. Its utilization example is as shown on below Fig. 1.



(a)Object recognition (b)SLAM

(c)Augmented reality

**Fig. 1.** Example of computer vision utilization

In this study, a system of identifying damage part of building using edge detection algorithm by converting photographed image to grayscale using light intensity(illuminance) after tracking ground structure in the air by mounting image camera in UAV is intended to be developed. In addition, structures could be managed efficiently by having inspector recognize facility condition and information without difficulty through UAV equipped with diversified sensor

## III. Main Subject

In this study, in order to supplement disadvantage of existing systems, development of a system that enables internal, external defect detection of high-rise facility and diversified inspections using UAV based diversified sensors and HD camera is proposed.

### *A. Total System Configuration and Hardware Specification*

Total system configuration to be proposed in this study is as shown on below Fig. 2.

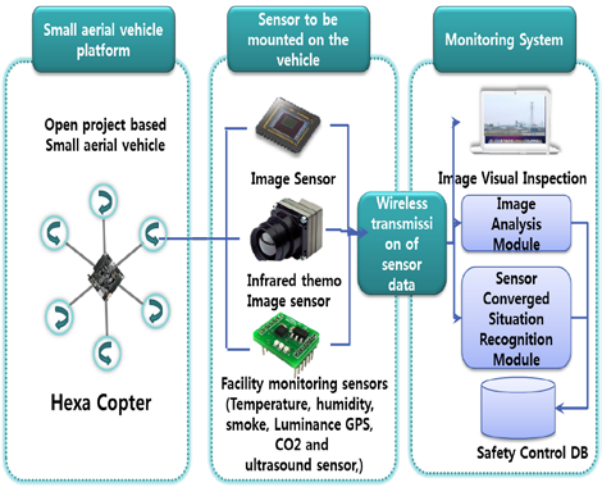



**Fig. 2** System Configuration

In order to perform safety inspection of structures, Mikrokopter based open-sourced UAV, Germany is used. Mikrokopter was developed into quardcopter (4), hexacopter (6) and octocopter (8) based on number of blade [5]. As a system of controling flight depending on altitude-hold (acceleration sensor), horizontality-hold (gyro sensor), posture stabilization function (pressure sensor), GPS is mounted in FC(Flight Control) board that controls flight and so, it is suitable for basic aircraft of UAV for safety inspection of structures [6]. By mounting image camera in UAV, image frame of UAV is supplied to tablet PC on the ground through a synchronization proces and tablet PC on the ground processes image of each entered frame. In addition, by mounting diversified sensors, more accurate safety control of structures could be ensured. General system outline is as shown on below Fig. 3.


**Fig. 3.** System Outline

Detailed hardware and functions of UAV to be equipped with multiple sensors are as follows

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TABLE I
DETAILED HARDWARE SPECIFICATION OF UAV

| Item | Specification |
|---|---|
| Diameter | 800mm |
| Frame | Aluminium |
| Weight (Battery excluded) | 3Kg |
| Propeller | 14 inch |
| Motor thrust | 1.5Kg/motor |
| Operation time | Over 30 minutes |
| Gimbal | 300mm(W)×300mm(H), Internal dia. 200mm |

MCU (Main Control Board) in which sensors will be mounted comprises multi Wii open-source base.

### *B. Sensor Convergence for Posture Control of UAV*

UAV to be used in this study is STM32 bit processor mounted Black32 board based hexacoper and it comprises 6 motors, 6 ESC (Electronic Speed Controller) that controls motor speed and 6 propellers. Fig. 4 shows Black32 board mounted with sensors.

**Fig. 4** UAV internal sensor mounting

In order to ensure flight of hexacopter by taking stabilized posture at the time of take-off and landing, balancing of blades facing with each other is very important.[7]

In order to measure posture of hexacopter, sensor is required and for exactly measuring roll, pitch, acceleration, gyro sensor are required and for measuring yaw, geomagnetic sensor is required. Acceleration sensor is a sensor measuring acceleration and its size is expressed in figure by dividing gravity acceleration into vector world of x, y, z axis. Gyro sensor is a sensor detecting angular velocity and as exact gradient measurement is difficult by accelerometer only in case that acceleration sensor measures other acceleration than gravity, it measures rotation angle. Therefore, gyro and acceleration sensor are used in convergence. Row, pitch value could be obtained by acceleration sensor but yaw value could be calculated by mounting geomagnetic sensor that measures global magnetic field [8].

Operation mechanism of gyro sensor is as shown on below Fig. 5.

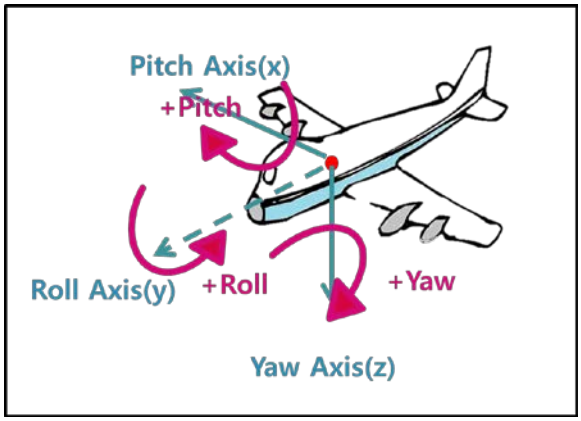


**Fig. 5.** Operation mechnism of 3-axis gyro

In this study, Kalman filter was used in order to obtain exact value by efficiently converging information acquired so far from sensors in posture stabilization of UAV.

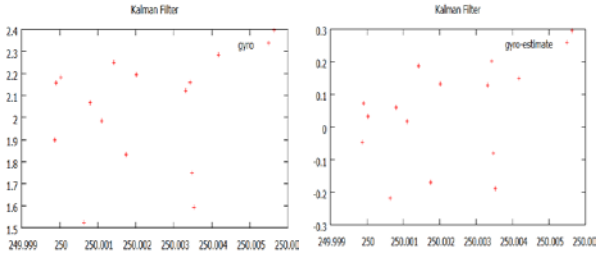


**Fig. 6.** Measurement of sensor data value through Kalman filter

Kalman filter developed by Rudolf Kalman in early 1960s is an algorithm being widely used in computer vision, robot, rocket, satellite, missile and control field [9]. This algorithm is estimating a new result after removing noise included in data by using past and new measurement data [10] and in this study, more exact image was intended to be processed through UAV positioning and posture control by using this Kalman filter.

### *C. Design and Development of multiple sensor mounted module*

Actually, inspector may require a lot of time and cost and experience a lot of difficulties due to exposure to risk if he wishes to check visually in order to confirm damage status of inspection site based on time difference by each season and day but by performing inspection through UAV mounted with sensors, such risk factors could be reduced and structures could be managed efficiently.

Therefore, in this study, by using diversified sensors including sensor of temperature, humidity, CO, CO2, Ozone, dust, VOC (detection of organic compound), safety of structures is intended to be inspected. In order to mount sensors in UAV, as large or heavy sensor module is detrimental to flight, flight stability is ensured by using small, light sensor module.

### *D. Development of multiple sensor data transmission technology*

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Multiple sensor data collected from UAV is required to be transmitted to monitoring personnel on the ground and in order to ensure transmission distance over min. 100m, IEEE 802.11n based wireless transmission module and 7dbi antenna are required to be composed. By visualizing sensor data being obtained from diversified sensors including sensors of temperature, humidity, CO, CO2, Ozone, dust and VOC (for detection of organic compound), data shall be processed.

By developing meta data management module that controls data type, unit, validity range of sensor data, sensor data of diversified forms are processed. Information could be managed more efficiently by implementing visualized module by each sensor data and displaying it in tablet PC monitor of the worker.

*E. Design of video camera mounted module*

Visual inspection is the most basic inspection method performing structural stability inspection but inspection of high-rise building facility by inspector with directly carrying inspection equipment is too dangerous and it requires a lot of time and cost. In this study, through more clear and precise photographing of video camera mounted in UAV, precision and efficiency of structural safety inspection are intended to be increased. Camera image is obtained by projecting dots of 3D space in 2D image plane. Therefore, conversion, movement and rotation of world coordinate to camera coordinate are taken place and in order to explain this coordinate conversion nature, a process of finding out parameter value is required and this is called calibration.

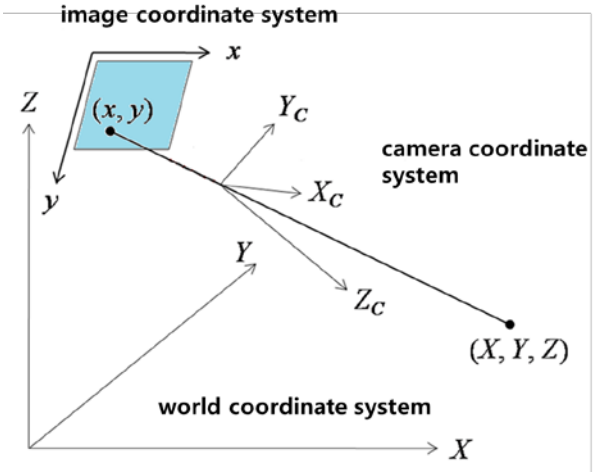


**Fig. 7.** Camera and image coordinate

As video camera to be mounted in UAV has to identify position of ground facilities in the air and perform inspection of external damage status and cracking, more precise and delicate image acquisition is required. Calibration is performed in order to correct camera distortion. Result of performing camera calibration is as shown on below Fig. 8.

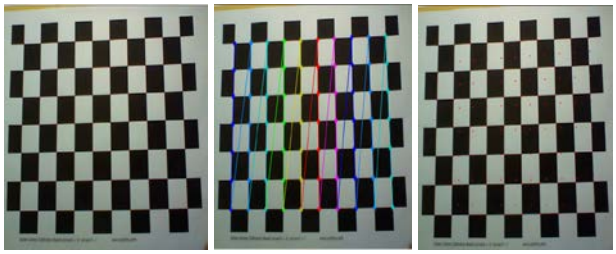

**Fig. 8.** Camera calibration

As a result of performing experiment with two image files, focal length was [762.873 766.547] +/- [26.743 26.669] and main pointer [298.977 231.074] +/- [3.814 6.803]. distortion [0.024516 -0.243971 -0.005740 -0.000509] +/- [0.030206 0.361247 0.000665 0.000902] and pixel error [0.26 0.22].

In order to transmit acquired image to the ground from video camera, IEEE 802.1x based wireless transmission technology was used. Motion JPEG video compression that may transmit clear image at every scene was used and safety of structure was identified promptly by transmitting image with transmission speed over 20-30fps and resolution of 4CIF/2CIF

*F. Development of image acquisition and processing technology*

In order to process images acquired from UAV, image processing technology is required. Image transmitted by video camera may be sometimes damaged and not clear and if interested area is desired to be observed, data could be managed more effectively by using image processing technology. In addition, as acquired image shows difference depending on climate or surrounding environment, image is required to be improved to be fit for intended purpose. As a technology of improving image, there are smoothing, sharpening and noise removal.

A work of extracting a specific area is called image analysis and it is mainly used for finding out size, form and contour line. In addition, in order to recognize image, following processing stage is required.

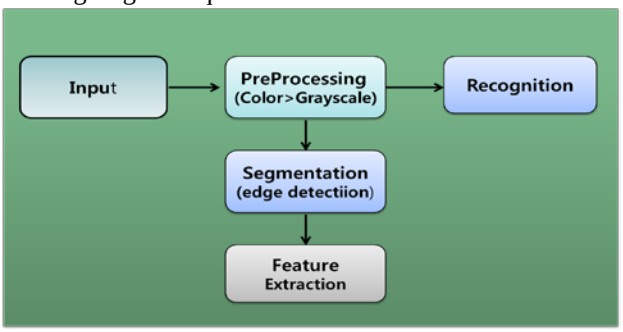


**Fig. 9.** Image recognition processing stage

In detecting internal, external damage status of structures by receiving input of color image being photographed by UAV, it is hard to process color image immediately and so, pre-treatment process of converting to grayscale is required. In order to change RGB color image to grayscale, it is required to change color information to light intensity information.

Various methods are available for changing RGB colour value to light intensity value and in this study, NTSC

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(National Television System Committee) method that is mainly used in analogue broadcasting system in our country and the USA is used. Required formula could be obtained as follows.

$$Grayscale = 0.2999 * Red + 0.587 * Green + 0.1114 * Blue \quad (1)$$

(a)RGB Color (b)Grayscale Conversion

**Fig. 10** PreProcessing

Image acquired from UAV requires more precise image processing through pre-treatment process and at this time edge detection method is used for removing noise of image. Edge is taken place at boundary between image object and object or object and background and it means boundary of object in image [11].

Detection technique using edge does not require many operations and such noise is usually identified by brightness change at edge that is boundary with background around image being entered. Edge information is used for detection of first differential function such as operators of Prewitt, Roberts, Sobel, second differential function such as Laplacian operator or many other methods. [12]

In most cases, as edge extraction mask is sensitive to noise, even small noise is frequently extracted by regarding it as noise. As a method of supplementing this disadvantage, there is edge extraction method using Canny mask and its objective is to extract strong edge by actually making such mask not to be sensitive to noise.

This algorithm presents a method of finding out edge that satisfies good detection, good localization and clear response.

In this study, Canny edge detection technique that is resistant to noise is used.

(a) Original image (b)Canny edge

**Fig. 11** Segmentation

Image processed like this uses extraction algorithm through image segmentation and its processing speed is fast and storage capacity could be saved as well. It has an advantage that after extracting characteristics using segmented image and comparing it with existing photographed image, its normality status could be determined without difficulty. Image processing technology like this is effective for identifying and managing structure condition.

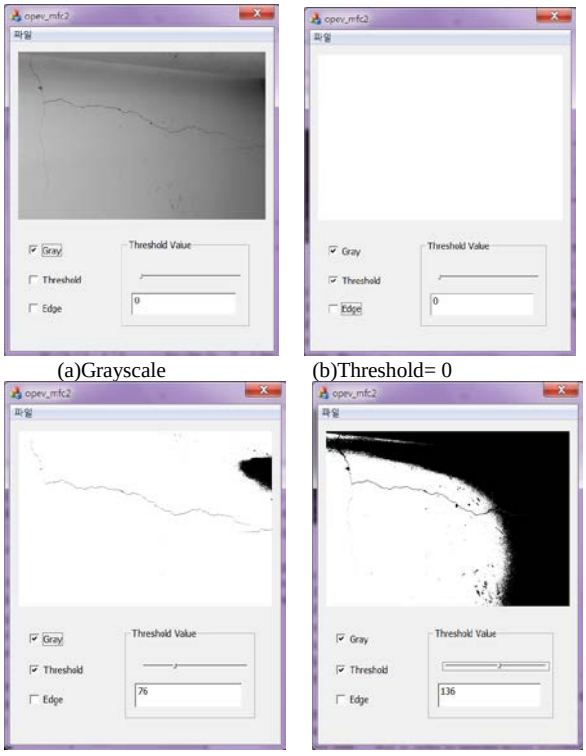
Pixel is basic unit of image and image is composed of numerously gathered pixels. Therefore, as the quantity of image data is relatively larger than that of general text data, considerable loss of time and data may be taken place during transmission. As the quantity of image being transmitted by video camera using UAV is relatively larger than that of general data, this feature is required to be considered.

In this study, image compression technology is used for removing overlapped or unnecessary data in order to store or transmit data efficiently. Image compression technology is usually classified into loss technique and lossless technique. As Loss technique reduces resolution at the time of compression and data is wasted, its quality is decreased. In order to restore image again, linear interpolation is used but it is hard to restore to original image. On the contrary, lossless technique makes no difference even though image is restored again after compression. In order to ensure fast image transmission in this study, Motion JPEG (M-JPEG) video compression is performed.

## IV. Experiment And Implementation

In this study, in order to perform inspection for cracking detection status of internal structures by importing video image photographed by UAV as a part of safety inspection of structures using UAV, window application program was implemented. Implemented image acquisition system is a program of identifying cracking status of internal, external structures by detecting contour line in order to obtain required information in screen after importing colour image file and converting it to Grayscale.

As a result of extracting cracking image of internal, external building, cracking image was extracted relatively well but very fine cracking image was not extracted as intended.




(a)Grayscale (b)Threshold= 0

(c)Threshold= 76 (d)Threshold= 136

**Fig. 12** Result of cracking extracting

## V. Conclusion

In this study, system design for structure safety inspection using UAV was suggested and a system processing

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photographed image was implemented. It could be realized that in order to process image acquired by UAV, noise was removed by using image processing algorithm and through more clear image, appearance of structure could be discriminated.

By providing more convenient working environment after visualizing data by mounting video camera and diversified sensors in UAV, more safe and objective inspection process and result could be obtained compared with existing method.

Based on future design, it is intended to be applied to safety inspection of T/L tower, plant smoking stack, bridges and piers, wind power generators of which access to workers is difficult and dangerous. In case of T/L tower, inspection of its corrosion and cracking by using UAV rather than manual inspection would be more safe and fast.

As inspection of plant smoking stack should be performed manually after stopping plant operation, a lot of cost is required but in case of safety inspection method using UAV, its inspection could be performed while operating plant continuously and analysis of gas being emitted during operation is enabled.

Besides, UAV could be utilized for safety inspection including exfoliation, cracking of concrete structures such as high-rise buildings and apartments and by mounting thermo-graphic camera in UAV, UAV could be used for detection using thermal sensing in wide area including forest fire watch-out. Therefore, it is expected that a system suggested in this study could be effectively utilized in safety inspection of diversified industrial fields in the future.

## ACKNOWLEDGMENT

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## REFERENCES

[1] Hundley, Richard, and Gritton, EugeneC, "Future Technology-Driven Revolutions in Military Operations", *RAND Corporation*, Document No. DB-110-ARPA, 1994.

[2] Jae-Ha Ryi, Wook Rhee and Jong-Soo Choi. "Effective Perceived Noise Level Prediction for a Propeller driven UAV by using Wind Tunnel Test Data", *Journal of Korean Society for Aeronautical & Space Science*, No. 41(1), pp. 10-16 , Jan. 2013.

[3] Min Goo Yoo and Sung Kyung Hong, "Target Tracking Control of Quadroto UAV using Vision Sensor", *Journal of Korean Society for Aeronautical & Space Science*, No. 40(2), pp. 118-128, 2012.

[4] Computer Vision Introduction, http://www.comp.nus.edu.sg/~cs4243/lecture/motion.pdf

[5] http://mikrokopter.de/en/home

[6] AscTec Hummingbird with AutoPilot User's Manual, Ascending Technologies GmbHC. J. Kaufman, *Rocky Mountain Research Lab., Boulder, CO*, private communication, May 1995.

[7] Gabriel M. Hoffmann, Haomiao Huang, Steven L. Waslander, Claire J. Tomlin., "Quadrotor Helicopter Flight Dynamics and Control: Theory and Experiment", *AIAA Guidance*, Navigation and Control Conference and Exhibit 20 - 23 August 2007, Hilton Head, South Carolina

[8] .Angelo M. Sabatini, "Quaternion-Based Extended Kalman Filter for Determining Orientation by Inertial and Magnetic Sensing", *IEEE TRANSACTIONS ON BIOMEDICAL ENGINEERING*, VOL. 53, NO. 7, JULY 2006

[9] Kalman, R. E. 1960. "A New Approach to Linear Filtering and Prediction Problems," Transaction of the ASME–*Journal of Basic Engineering*, pp. 35-45 (March 1960)

[10] Gan. Q, Harris. C. J, "Comparison of two measurement fusion methods for Kalman-filter-based multisensory data fusion", *Aerospace and Electronic Systems*, Vol37, Issue 1, pp.273-279, Jan, 2001

[11] Hea-jung Lee, Sung-tae Jung, Suck-tae Joung, "Noise Elimination and Edge Detection based on Fuzzy Logic", *The journal of the Korea Institute of Maritime Information & Communication Sciences*, Vol7, No3, pp.506-512, 2003

[12] S. E. El-Khamy, "A Modified Fuzzy Sobel Edge Detector.", *Radio Science Conference*, pp. 1-9, 2000,Feb, 22-24.

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