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Unmanned Aerial Vehicle Based Automated Inspection System for High Voltage Transmission Lines

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Abstract—This paper describes a basic idea of a fully automated inspection system for the high voltage transmission line. The automated system developed on the unmanned aerial vehicle software and hardware. The high voltage transmission line inspection is a time consuming dangerous job due to the high voltage risk, and the height and accessibility of the towers. Today, numerous researchers and companies started to use the unmanned aerial vehicle in the different field of industry. One of the main space for this usage is renewable power generator and distribution of electricity to long distance. The new aspect of this paper is to develop the fully automated inspection system for high voltage transmission line and to create software and hardware for such automated system.

Keywords: power line; inspection techniques; architecture; man-machine system; power line inspection

INTRODUCTION

All over the world, High Voltage Transmission Lines (HVTL) are used for distributing electric energy from the generator to the consumer/customer. The reliability of the HVTL directly affects the performance of the entire power system. Due to the outdoor condition and the usage period, there are various kinds of failures can be detected on the transmission line. Such failures have to be detected and fixed immediately. The power sector parties started to implement new technology into the inspection and maintenance of the power system. Nevertheless, the HVTL inspections and maintenance are still performed by the human. This is one of the essential issues to be solved without time, cost-saving, safe and efficient approaches.

In many countries, human expert based traditional inspection techniques are is still actively using in industries. At the same time, it is being while since the helicopter based examination method is used in developed countries [1]. The helicopter based HVTL inspection system is much efficient than the conventional method, but the one major drawback is the expensive cost. According to this aspect, the manned aerial vehicle-based method is not well known in many countries.

There is a huge number of research done in HVTL inspection robot area. Also, some of them are successfully implemented and already on the market. Today's most leading technology in robotic is the unmanned aerial vehicle (UAV) as well as it has been using in different ways in some developed countries and in companies [2]. Aerial inspection is one of the main applications of UAV. The energy sector is one major customer which is using it in a high voltage transmission line inspection.

Drone is called as an unmanned aerial vehicle; even so, this is not a fully automated device. The unmanned vehicle means there is no human on the board. However, the pilot still controls all actions which are flight and mission processes.

UAV-based HVTL inspection system has significant advantages compared to conventional human-expert based and helicopter based methods. It reduces inspection cost and time also increases the workers' safety. In additional it provides a possibility to inspect and serve the active working high voltage power lines. In other words, the constant, frequent, voltage independent inspection will increase the HVTL reliability dramatically.

Power line aerial inspection processes and results are still depending on the human ability. The flight time of UAV is directly depending on power consumption and battery capacity. Gathering reliable data in that short time is a hard job which requires a solid background of flight and teamwork ability from the specialists. Therefore, well-trained, experienced professionals are required to do acceptable, high-quality inspection. According to this fact, there is no chance to do the inspection for the engineers and workers of the company. The perfect solution is the UAV based fully automated HVTL inspection system (Fig 1).

Fig.1. Powerline inspection technique development

Research goal

Our research target is to develop and implement the UAV based fully automated HVPL inspection system's hardware and software architecture.

To execute a fully automated mission, a multivariable function will have the main role in the software. In other words, due to building perfect man-machine cooperation, the factors which represent the environmental and the mission condition will be included in the software with this function.

Expected results

UAV based fully automated system improves the reliability and quality of the power line inspection process, also decrease risks which are cause by human skill and fault. As a result, no experienced pilots are required, and electrical experts will be able to do the inspection on their own. Also, image processing approach will provide real-time automated fault detection of power line.

STATE OF THE ART

The companies which provide the UAV-based services are rapidly increasing in last few years, as well as they are offering different types of services by contract. The renewable energy sector is one big employer of the UAV-based services. In general, the drone-based inspection is trending technology for solar panel and wind turbine services and maintenance.

The articles which are posted in WindSpec [3], Ascending Technology [4] and ING Robotic Aviation [5] company websites, proving that drone-based inspection takes 1.5-3 hours to completely inspect one wind turbine, which is 3-4 times faster than the conventional human-expert based method.

Another point is, Chris Bley who is chief executive at InspecTools said that UAV-based inspection cover up to 10-12 wind turbines daily, also he mentioned that fully automated UAV-based system could increase the inspection number up to 15-20 per a day [6].

According to the latest report from Navigant Research, the global investment on drone and robotic technology for transmission and distribution is expected to total nearly $16.2 billion from 2015 to 2024, also annual revenue from this sector is expected to grow from $131.7 million to $4.1 billion in this period of time [7].

Dramatically increasing application of the drone is demanding the next level of technology approach in UAV. There are numbers of research done in automated inspection area and first of them is on the market. For example, Optimus-1 is fully automated industrial aerial inspection system provided by AIRobotics [8].

MATHEMATICAL MODEL

UAV-based fully automated HVTL inspection system is human independent, onboard, embedded system. Autonomy level of the unmanned system (ALFUS) is evaluated by following three factors [9]. These are:

- Environmental complexity
- Mission complexity
- Human independence

These three main factors represent the actual power line inspection situation. So, with help of this influence factors, we can design the unmanned system mathematical model. The equation (1) of the unmanned automated system can be written in the following form.

$$C = \sum_{i=1}^{3} w_i IF_i \qquad (1)$$

IF_1 - Environmental complexity factor

IF_2 - Mission complexity factor

IF_3 - Human-machine interaction

IF_i are the main influence factors of the automated system also w_i is corresponding weight factor of these inputs. As well as, the main input aspects can be formulated by the other auxiliary elements (equation 2).

$$IF_i = f(SF_{i1}, \ldots SF_{ij}) \qquad (2)$$

SF_{ij} are the sub factors which express the three different major aspects of unmanned system autonomy level. For instance, the wind direction and speed, air humidity and weight, electromagnetic field influence, UAV position and behaviors, mission plan, process and conflict, and human direct command are represented by these sub factors.

AUTONOMY

UAV-based fully automated power line inspection system is an embedded system. The hardware and software have to be designed together to perfectly implement. The hardware architecture of the inspection system consists of two main parts which are Ground Control Station (GCS) and UAV, as shown in Fig 2.

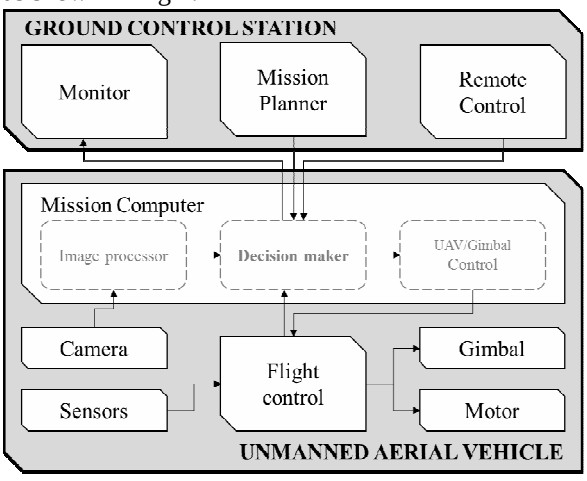

Fig. 2. Hardware architecture of UAV-based fully automated HVTL inspection system

The UAV have to accomplish the inspection mission itself, also it has two main computer/board.

1. Flight Control Computer (FCC) is UAV's main flight control system.

2. Mission computer (MC) is for controlling the mission procedure. Mission computer has a function to do automate inspection with assist of the FCC and with other mission sensors and actuators. In other words, Mission Computer will make decision based on mission plan, operators' direct command, environmental and UAV situations to accomplish fully automated, human independent mission.

These decisions will be made by software. Service oriented architecture will be used in the software architecture which is shown in Fig 3. There are numbers of special purpose software functions which are divided in to four major groups [10].

- *Flight service:* This group of software components is designed for take a control of flight by cooperating with the Flight Control Computer to accomplish the aerial inspection mission. Also, the Flight service supports the mission and awareness service with UAV behavioral data to carry on the mission process.
- *Mission service:* These parts of software will provide mission planning, management, monitoring and real-time data exploitation services.
- *Image processing service:* This service consists of computer vision based inspection object recognition, tracking and UAV navigation software components.
- *Awareness service:* Flight and Mission Services are for the mission management in normal conditions at the same time the Awareness Services are in charge of monitoring surroundings conditions and overtake mission management in critical, unexpected conditions.

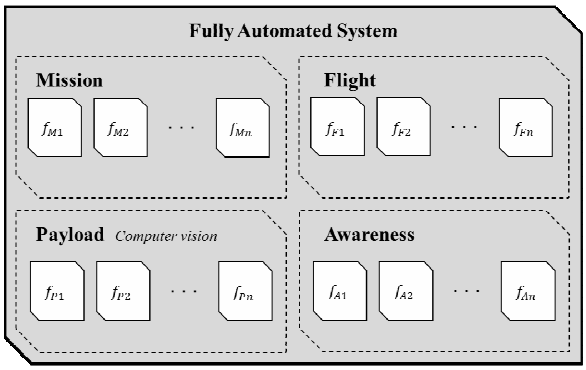

Fig. 3. HVTL inspection fully automated system software architecture
(Unmanned aerial vehicle services abstraction layer [10])

THE FIRST STEPS OF THE RESEARCH

This research is performed by the experts from three different parties which are Technical University of Chemnitz (TU Chemnitz), and Mongolian University of Science and Technology (MUST), and Mongolian National Power Transmission Grid (NPTG).

In early 2016, the research program was initiated at the TU Chemnitz under the program named APOLI. The initial technical concept, prototyping and software developments of the mission computer and UAV have been done at the TU Chemnitz.

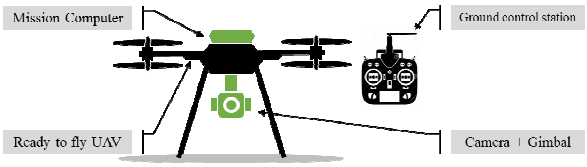

Fig. 4. HVTL inspection UAV

At the second phase of the research, the UAV was tested in the field with the electrical experts from NPTG in August 2016. During this field experiment, valuable data was collected from 299 minutes lasted, 23 flights which performed on 203.8km long "Kharkhorin - A, B" 110kV HVTL. The inspection data was used for the improvement of the UAV performance, and provided the raw data of image processing software development [11].

Current research task is to develop the fully automated inspection system hardware-software co-design solutions. In hardware side, i.MX6 ARM Cortex-A9 mission computer is updated by Odroid XU4 computer and the performance of gimbal and mission sensor are improved by the new hardware solution.

Fully automated HVTL inspection system has duty to detect following faults:

1. Insulator fault
2. Cable fault

Computer vision have sufficient potential to detect these kinds of faults. In other words, Mission Computer of automated system runs the image processing algorithm to examine the inspection objects automatically.

The first task of image processing algorithm is to detect powerline insulator from image/video data. The following task is to control the gimbal movement to continuously track the inspection object (Fig 5.a). With this approach, it will become possible to gather high quality inspection data and possible to do fully automated damage assessment on it.

The second main task is to do an aerial inspection in powerline cables/conductors, while flying from one tower to another tower. But, due to the electro-magnetic radiation of the HVTL, the conventional positioning and orientation sensors are working not properly. So, UAV will use a vision-based flight control which is for real-time inspection object recognition and tracking, also for UAV navigation (Fig 5.b).

TABLE I. INITIAL EXERIMENT DATA

№	Flight				Tower		Sensor	
	Type	*Mode*	Date	*Time /min/*	*ID*	*Type*	*Camera, Gimbal*	
1	Test	Manual	8/22	1	831	У110-2	Basler acA1300	2D
2		Manual	8/22	1	831	У110-2		2D
3		Manual	8/22	5	831	У110-2		2D
4		Auto	8/22	5	831	У110-2		2D
5		Auto	8/22	8	831	У110-2		2D
6		Auto	8/22	5	831	У110-2		2D
7		Manual	8/22	5	831	У110-2		2D
8		Manual	8/22	10	831	У110-2		2D
9	Inspection	Manual	8/22	20	831	У110-2		2D
10		Manual	8/22	20	832	ПБ110-8		2D
11		Manual	8/24	20	2	У110-2	Sony HDR-CX410VE	-
12		Manual	8/24	20	3	У110-2		-
13		Manual	8/24	20	128	У110-2		-
14		Manual	8/24	18	129	У110-2		-
15		Manual	8/24	18	130	У110-2		-
16		Manual	8/24	18	131	У110-2		-
17		Manual	8/24	15	132	У110-2		-
18		Manual	8/24	15	134	У110-2		-
19		Manual	8/24	15	135	У110-2		-
20		Manual	8/24	15	136	У110-2		-
21		Manual	8/24	15	137	У110-2		-
22		Manual	8/24	15	138	У110-2		-
23		Manual	8/24	15	139	У110-2		-
Total				**299**	**15**	**2**		

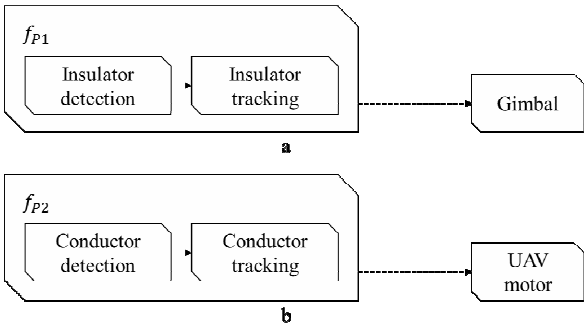

Fig. 5. Image processing sub functions
a. HVTL insulator recognition and tracking,
b. HVTL cable recognition and tracking

CONCLUTION

UAV-based power line inspection system has powerful advantages which are time- and cost-saving, safe, reliable and possibility to inspect without shutting down the powerline. However, it is still under control of human and still limited by human ability. The perfect solution of most robust, reliable HVTL inspection method is UAV-based fully automated system.

In this paper, HVTL fully automated inspection system initial mathematical functions have designed. Next task is to define the main influence factors (IF_i) with the sub factors (SF_{ij}). According to this approach, the mathematical model of UAV-based HVTL fully automated inspection system will complete.

Additionally, the main framework of the hardware and software architectures are designed,

also the development and implementation of these two main parts shall be performed in the near future and as result of that, UAV-based fully automated HVTL inspection system will be implemented.

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REFERENCES

[1] Helicopter Links, ‘Helicopter Companies, Operators for Utility Work, Powerline, Pipeline and Surveying Inspections’, [Online] Available: http://www.helicopterlinks.com/utility/ [Accessed: 15- Feb- 2017]

[2] Margi Murphy, Christina Mercer, ‘22 companies using drones right now: Amazon, Asda, the BBC and more - Here's how drones are being used in 2017’, 2017. [Online] Available: http://www.techworld.com/picture-gallery/personal-tech/best-uses-of-drones-in-business-3605145-3605145/ [Accessed: 25- Feb- 2017].

[3] ‘Compare the time it takes to inspect just one tower’, [Online]. Available: http://windspect.com/. [Accessed: 11- Feb- 2017].

[4] ‘Renewable UK: Cyberhawk launches special wind turbine inspection service’, 2015, [Online]. Available: http://www.asctec.de/en/renewable-uk-cyberhawk-drone-wind-turbine-service/ [Accessed: 11- Feb- 2017].

[5] Inside Unmanned Systems, ‘ING Robotic Aviation Uses Responder UAS for Turbine Blade Inspections’, [Online] Available: http://insideunmannedsystems.com/ing-robotic-aviation-uses-responder-uas-for-turbine-blade-inspections/ . . [Accessed: 15- Feb- 2017]

[6] Jason Deign, ‘Fully automated drones could double wind turbine inspection rates’, 2017. [Online]. Available: http://analysis.windenergyupdate.com/operations-maintenance/fully-automated-drones-could-double-wind-turbine-inspection-rates [Accessed: 10- Feb- 2017].

[7] L. Lorenz, ‘Annual Revenue for Drone and Robotics Technologies for Transmission and Distribution Is Expected to Reach $4.1 Billion by 2024’, 2015. [Online]. Available: https://www.navigantresearch.com/newsroom/annual-revenue-for-drone-and-robotics-technologies-for-transmission-and-distribution-is-expected-to-reach-4-1-billion-by-2024. [Accessed: 1- Feb- 2017].

[8] Gwen Ackerman, ‘Secret Israeli Drone Maker Has Funds, Clients, Autonomous Robots’, 2016. [Online]. Available: https://www.bloomberg.com/news/articles/2016-06-21/secret-israeli-drone-maker-has-funds-clients-autonomous-robots . [Accessed: 13- Feb- 2017]

[9] Hui-Min Huangi, Kerry Pavekii, Brian Novakiii, James Albusi and Elena Messinai, “A Framework For Autonomy Levels For Unmanned Systems (ALFUS),” in Proceeddings of the AUVSI’s Unmanned Systems North America 2005, June 2005, Baltimore, MD.

[10] E. Pastor, C. Barrado, P. Royo, J. Lopez and E. Santamaria (2009), “An Open Architecture for the Integration of UAV Civil Applications,” Aerial Vehicles, Thanh Mung Lam (Ed.), InTech, DOI: 10.5772/6488.

[11] Enkhjargal Khaltar, Uranchimeg Tudevdagva, Chinbat. D, Erdenetsogt. B, Stephan Blokzyl and Batbayar Battseren, ‘The beginning of Unmanned Aerial Vehicle based inspection of HVTL’, *Electric Power and Engineering*, vol. 156, pp. 23-27, Feb 2017, Mongolia.

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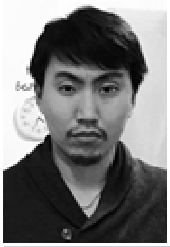

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