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Development of Multi-Tentacle Micro Air Vehicle

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***Abstract*— We introduce a developmental stage of multi-tentacle MAV (micro air vehicle) platform. It is based on a four rotary wing aerial platform such as a quadrotor system and three of 4 DOF (degree of freedom) tentacles attached at the bottom of it. Unlikely mobile manipulating research which focuses more on the stability and control of manipulators and floating platform, a multi-tentacle system presented in this paper is intended to suggest a new paradigm of small scaled aerial robotics research and to show the proof of concept of them by experiment. Newly integrated and developed multi-tentacle aerial vehicle can have extended locomotions compared currently existing flying-only vehicles such as vertically and upside down perching capability, inclined or rough surface landing capability, and object pickup and release. Furthermore, control of a particular motion of tentacles adds propulsive force for taking off as birds or flying animals do.**

Keywords – multi-tentacles, micro air vehicles, aerial robot

I. INTRODUCTION

Locomotion in robotics usually means types of motions. Most of animals in nature have more than a single locomotion. For example, birds can fly, walk, perch, and catch food as shown in Fig. 01. Octopus can swim with or without using tentacles, and catch small fish. We human can also walk, run, jump, and even swim. We all interact with environment somehow either passively or actively. Passive interactions are one-directional communications in general. For example, if a robot is flying to search for a target or an object without any type of physical contact with environment, it is a passive way of interaction. Meanwhile, active ones are bi-directional. A robot can change surroundings of environment. Between environment and system, they give and take inputs and communication with each other by using additionally functional parts of body or sensors. As an example, birds' legs are not only intended for walking or perching but also for catching preys and generating additional forces when they take off and even when they land on rough surfaces. In summary, almost all the animals on earth use some types of arms, legs, or tentacles for their interactions with environment and aerial robots also need them for the same reason and purpose. There is no doubt of great advantages in unmanned aerial vehicles or autonomous aerial robotics in various research and development topics and also in military and commercial applications. By the nature of unmanned or autonomous aerial robots with flying only capabilities, they are mainly used for search and rescue, surveillance, monitoring for survey purposes so current and most of aerial robotics research addresses problems associated with a typical passive way of communication, without any interactions with environment, and limited to have a single locomotion (flying-only motions) for aerial applications. So they are far from what animals do with their arms or legs for multi-locomotion movements.

Figure 01 A Bird Taking-off: Courtesy of J R Compton

Figure 02 Multi-Tentacle MAV Prototype in Landing Mode

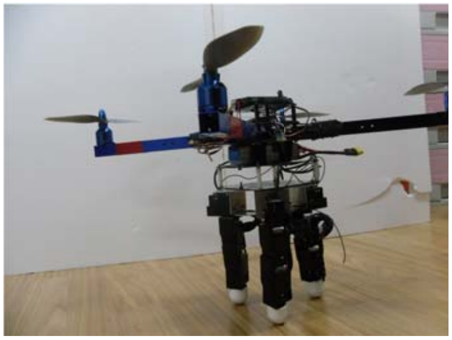

Figure 03 Multi-Tentacle MAV Prototype in Landing Mode

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II. OBJECTIVES

The main objective of this research presented in this paper is to have an integrated aerial robotic platform with multiple tentacles attached so we show the research potential of the developed system doing various motions and in-situ tasks as other animals do shown in Fig 02 and 03. To attach a gripping mechanism is critical to have another locomotion and for an aerial robot to actively interact with environment.

Unlikely mobile manipulating in ground robot problems, aerial platforms are difficult to stabilize and control even without any disturbances. Manipulators in floating platforms keep changing the center of gravity position and inertia specially when they interact or have physical contact with environment. Next section of related works, we compare multi-tentacle MAV with similar research activities such as mobile manipulating, dynamic gripping mechanism, and multi-locomotion aerial platforms.

In this paper, we present the initial stage of integrated system of multi-tentacle micro air vehicle performing various locomotions and tasks. Also we describe hardware and control of each aerial and tentacle system in detail. Subsequently, we conclude with future work and potential of this research.

III. BACKGROUND

A. Manipulators on Ground Systems

Manipulators on ground systems are getting more popular in various fields both in commercial and military applications due to their ability to interact with their environment. For example, NASA's Robonaut, University of Massachusetts' uBot, Willow Garage's PR2, and CMU's HERB all include dual manipulators fixed to a mobile robot. But all these systems above are mainly focused on the coordination between mobile platforms and manipulator to perform a given task. By the nature of mobile platform, the weight of manipulator is no longer an issue. Highly dexterous manipulators with high DOF of dual arm systems could be easily attached to the mobile platform with various sensors. But this mobile robot based manipulators are somewhat different from what we are pursuing.

B. Manipulators on Aerial Systems

Manipulators on aerial systems are significantly different from one on ground vehicles. They typically have more and different difficulties than traditional ground robots doe in terms of stability specially when their interacting with environment using the manipulator. It is crucial and most difficult task to stabilize the platform. Drexel University [01], one of leading groups in mobile manipulating on aerial platforms, works on the development of highly dexterous manipulator on a gantry platform for now assuming future UAV technologies will enable to handle tremendously large amount of payload in the future. This approach is still meaning in some sense since they collect experimental data of change of dynamic properties of manipulator as the function of its various motions but still it is far from what we pursue. Also aerial platforms with either a single or dual arm manipulators used require a high precision platform control even with highly dexterous manipulators.

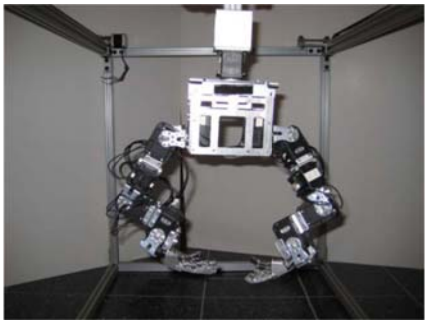

Figure 04 Mini-Gantry Test Rig with Dual Manipulator Attached of Drexel University

C. Multi-Locomotion Aerial Systems

Recently many researchers devoted into developing multi-locomotion systems inspired by nature. Examples of animals that combine self-deployment with gliding can be found in many different species with different evolutionary origins. Gliding lizards [2,3,4,5], locusts [6], flying fish [7,8], gliding geckoes [9,10], gliding ants and spiders [11,12,13,14], gliding squid [15,16], gliding frogs [17,18], bats [19], gliding mammals [20,21,22,23], gliding snakes [24,25] and many birds use combinations of jumps and gliding flight.

Some of the most successful hybrid robots were those that operate in the aquatic and terrestrial domains. One of the first of these was a water-tight version of RHex [26]. The primary compromise in the development of the hybrid vehicle was in leg design. Boxybot [27] was developed at the Swiss Federal Institute of Technology, Lausanne mostly as a platform for testing central pattern generator efficacy in hybrid swimming/crawling robots. Few have researched small, multi-mode robots capable of aerial and terrestrial locomotion. Among these, the Entomopter [28] was perhaps the most ambitious. Reciprocating Chemical Muscle [29] was developed to drive Entomopter's 15 centimeter flapping wings at 35 Hertz. Another is the system developed at Swiss Federal Institute of Technology, Lausanne, the Self Deploying Microglider [30], which is a 10 gram vehicle that can jump and glide moderate distances. Another is MALV (Micro Air Land Vehicle). A rigid leading edge, chord-wise compliant wing design is the basis for MALV's aerial locomotion. A chord-wise compliant wing (first developed and implemented in the University of Florida, fig. 05) overcomes many of the difficulties associated with flight on the MAV scale.

Figure 05. The chord-wise compliance of a flexible wing allows for passive-adaptive washout, increasing stability of the aircraft by Courtesy of Univ. of Floria

But none of these multi-locomotion aerial platforms uses actual hands or grippers to interact with environment.

IV. MULTI-TENTACLE SYSTEM

In this section, we introduce various motions and potential tasks of multi-tentacle MAV could do.

a) Object Grasping

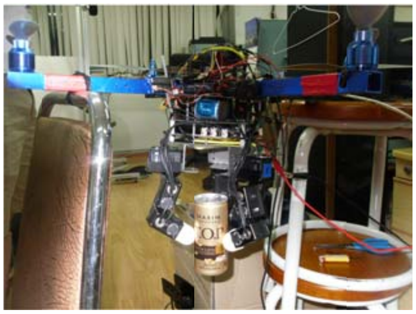

Figure 08 Multi-tentacle MAV system is holding an object.

In fig. 08 and 09, three tentacles can hold various weighted and sized objects. The tip of each tentacle is covered with rubber material so the slipping is minimized.

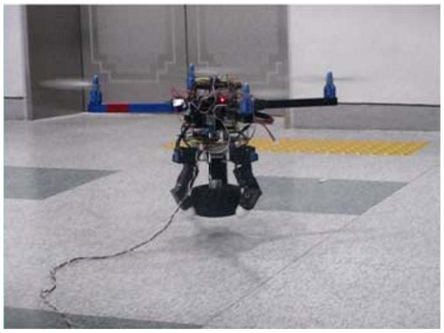

Figure 09 Multi-tentacle MAV system is holding an object.

b) Vertical Perch

Figure 10 Multi-tentacle MAV system is perched vertically.

Figure 10 and 11 show that the multi-tentacle vehicle is holding an object to attach his body vertically. The flight motion and control to be attached is under development yet. However; it shows that without any other material or specially designed mechanism, it can perch using his tentacles.

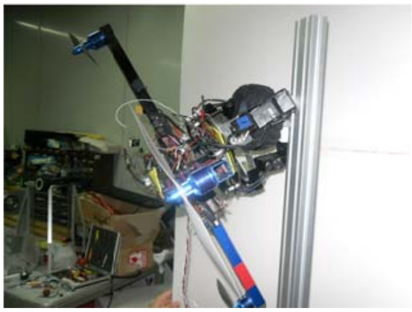

Figure 11 Multi-tentacle MAV system is holding an object.

c) Upside-Down Perch

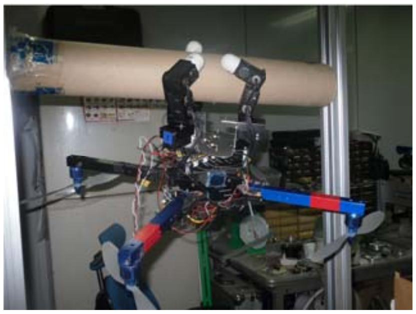

Figure 12 Multi-tentacle MAV system is holding a bar.

This figure 12 and 13 show that even upside-down perch is possible using multiple tentacles. The force generated by them is enough to hold the whole body perched up-side down.

Figure 13 Multi-tentacle MAV system is holding an object to perch upside-down.

d) Propulsive Take-Off

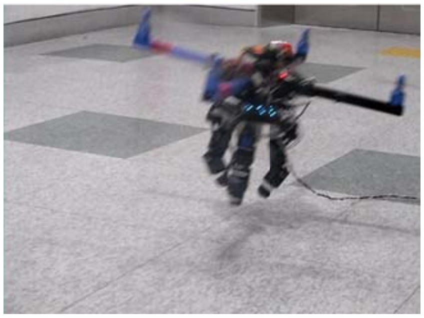

Figure 14 Multi-tentacle MAV system is taking off.

Figure 14 shows that using multi-tentacles, the quadrotor MAV could have additional force to take off. Tentacles are not only being used to grab objects but also to add propulsive force for the aerial platform to take-off when needed as other animals or birds do when they leap for flying or jump.

e) Landing and Stand

Figure 15 Multi-tentacle MAV system stands all tentacles stretched.

Figure 16 Multi-tentacle MAV system lands on flat surfaces.

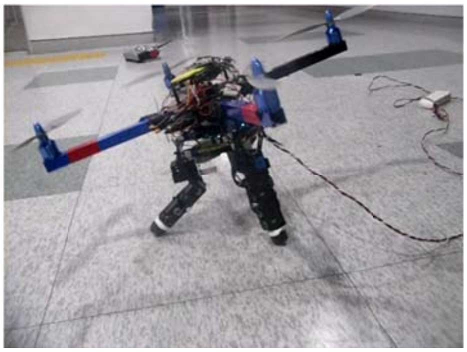

Figure 17 Multi-tentacle MAV system lands with one tentacle bend.

Figures above (15-17) show different landing modes of the system. Tentacles are used even for landing gears for different surfaces. Coordination of tentacle motions could be selected and controlled depending on the terrain conditions. Figure xx pretends that the vehicle lands on rough surface or terrain where other vehicles can not.

V. TENTACLE SYSTEM AND CONTROL

TABLE 1
Specification of Tentacle System

Number of fingers	4 tentacles	
Number of joints	4 x 4 = 16 DOF	
Actuator module	type	DC motor
	Gear ratio	1:369
	Overdrive torque	0.7 [Nm]
Weight	total	0.68 [kg]
	finger	0.17 [kg]
Joint resolution	0.002 [deg]	
Communication	type	CAN
	period	333 [Hz]
Payload	0.5 [kg] each finger	

Each tentacle consists of 4 DOFs, and the total numbers of joints are 16 DOFs as shown in table 1.

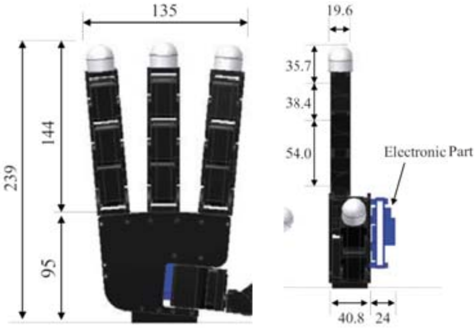

Figure 18. Appearance and size of three tentacles

The specific structures of a tentacles is described in Fig. 18. It is shown that a tentacle is built-in actuation components of actuator, gears, and electronic units. The most focused point of this design is the adoption of the RC servo module. As shown in Fig. 19, the module is designed as the axes of actuator and joint as parallel, and spur gears is used as a device of power transmission. The module provides miniaturization of tentacles and worthy back-drivability of joints.

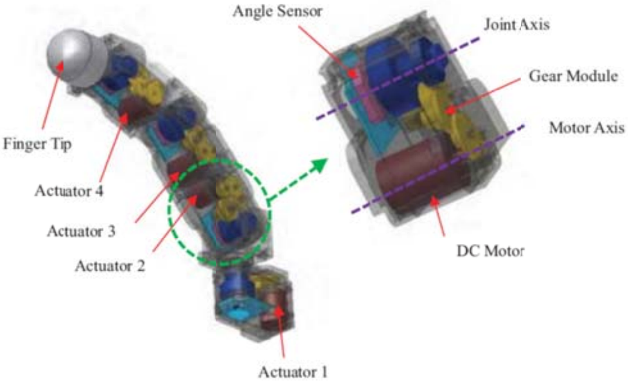

Figure 19. Appearance and size of three tentacles

For the tip of each tentacle, we chose a frictional soft tip with silicone. The frictional soft tip makes it possible 1) absorb impacts under collision between tentacle end and an object, 2) make area contact with an object, and 3) avoid a slip on the surface of a grasped object. This tip plays an important role in an increased of the stability grasping.

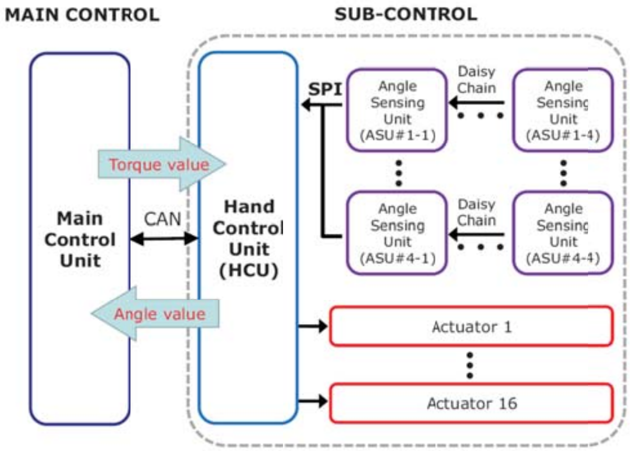

Figure 20. Block diagram of electronics and communication

The block diagram of electronics and communication of tentacles is shown in Fig. 20. It consists of two parts, a main control part and a sub-control part. The main control is operated in an external PC and the sub-control is achieved in MCU (Micro-Controller Unit) embedded in tentacle system. Two parts are connected with CAN communication. As MCU, 'TMS320F28335 DSP' from Texas Instruments is used, and the communication between DSP and ADC for joint angle values is SPI. The sub-control unit is composed of two layers: DSP and motor drive parts shown in Fig. 21.

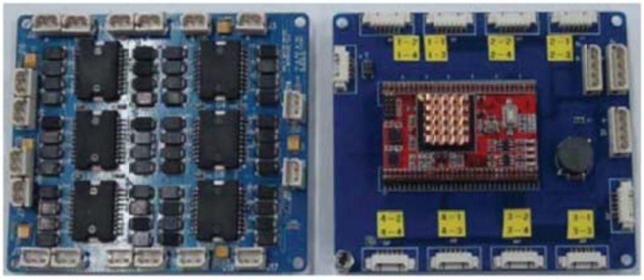

Figure 21. Sub-control unit

These units are attached to the bottom of the quadcopter.

VI. CONCLUSION

In this paper, we present the first trial of developing multi-tentacle MAV Quadrotor platform which enables to perform various tasks in application. The control and coordination of tentacles select different landing modes and object grasping. Assuming the motion generation of flight, the multi-tentacles even could be used to perch vertically and up-side down position as some birds do.

VII. FUTURE WORK

Detail hardware and software description will be added in this paper. Subsequently, the control logic and software suite for controlling the integrated systems will be added.

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