



The Development of Tethered Drone Station

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Abstract: A drone is a type of unmanned aerial vehicle (UAV) where the aircraft is flying without a human pilot on board. For a tethered drone, there will be a ground power station that enables the drone to fly with an ultimate flight duration. The tethered drone station is connected to the drone using a wire cord to supply the electrical energy. As the drone flying away, the tethered system is required to feed a longer wire to the drone. Although several tethered drones feeding system designs are available, those published patented, and no detailed explanation on the system programming. Hence, this study is conducted to self-develop a suitable system for the wire control mechanism. Few practically possible design concepts are introduced in this thesis. Using load feedback signal was selected as the best option to control the wire stretching and feeding mechanism. A complete design was produced, utilizing load cell as a sensor to provide load data as the input signal to the Arduino Uno microcontroller. Thresholds load conditions were programmed into the microcontroller for the decision-making process on the suitable motor response (retract or feeding rotation). In general, the response conditions are default motion is retracted motion until the motor undergoes the feeding motion when the load is higher than the second threshold. As the system validation, several threshold conditions in the range of 50N to 600N were tested at the end of this development process. From the analysis, the design was found able to provide suitable responses at accurate pre-set threshold conditions with the average percentage errors of 1.85 and 1.07 for the retract and release responses respectively.

Keywords: Tethered Drone Station, Solidworks, Autonomous Retraction System, Unmanned Aerial Vehicle (UAV), Sensor System.

1. Introduction

An unmanned aerial vehicle (UAV) or drone is an unmanned aircraft that being entirely controlled by a remote human or computer. The innovation of the drone which able to perform a various task such as infrastructures inspection, measurement, security, and disaster response has been develop continuously. Tethered drone is also an example of unmanned aerial vehicle. Fundamentally, a tethered drone or un-maned air vehicle (UAV) is associated with the ground control system which known as its station. The drone station is the control center of UAV system, and it gives the plausibility that UAV can perform different errands. There is also various type of tethered drone station that already exist

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which each of them plays different function that suit the purpose of the tethered drone itself. Since the ground system consist of multiple applications, it has successfully attracted many research to contributes into the study purpose on the optimizing the application of the tethered drone. The tethered system is the main challenge in the development of tethered drone.

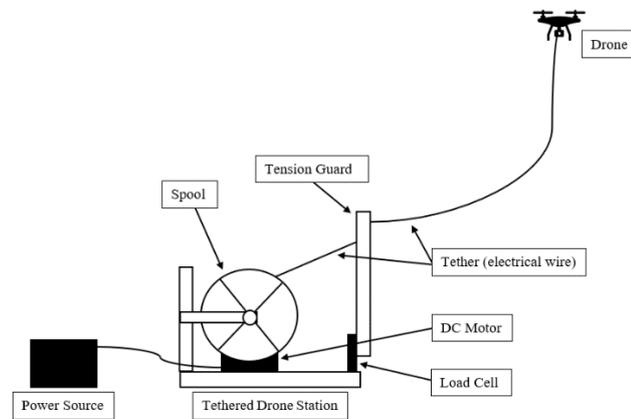


Figure 1: Diagram of overall system of tethered drone

The application of drone in the field that required a long endurance operation such as aerial monitoring, surveillance, reconnaissance, communication, and electronic demand a drone that able to flight continuously for a long period (Nicotra et al., 2017), therefore battery that supply the power to the drone should be replaced frequently. To avoid the lead time of changing battery there is a need to develop a tethered drone. Research to development of tethered drone is limited, add most of the design are published in a patented document which restricted the application of those system in our in-house development drone prototype. Generally, this system consists of ground power module, air power module and retraction system. In this research, several available types of tethered system are assessed and next to be decide which is the better option to be applied for research. Initially, there are three types of tethered system that been listed which are firstly, a drone station that applied a retraction system using feedback (motor and a sensor) or motor and switch for its modus operation, next, a drone station that applied a continuous retract concept and lastly, self-retract control concept. All these three listed concepts will be compared as to pick the best option for the retraction system of the drone station. As tethered drone is mainly dependent on the tether that attached to its station, the best approach must be select to ensure the drone station respond with the movement of the drone.

2. Materials and Methods

2.1 Tethered system

Tethered system will consist of three important component which are ground power module, air power module and retraction system. A power module is the arrangement of module to form a housing that functions for the unit that is placed here is to drive the motor and control the operation of the high-power machine. Power module will be the centre of which the control mechanism of the system for a machine will be works. The development of tether drone station included the ability of the station to empowering the drone continuously. As the main feedback for an untethered drone is its limited battery sources which only depend on a small capacity of battery, power source that been supply from the drone through tether is a solution to a long period of flight time for a tethered drone.

Air power module is the delivery of the current from the ground station to the drone. the power will be supplied through the tether. There will be an AC-DC converter that be install to the drone. As the current initially being transfer in form of alternating current from the base, it should be converting into DC current before empowering the drone. The flying drone and the ground station is connected through

tether (Bolognini & Fagiano, 2020). The tether can perform a various task such as transmitting energy (Bolognini & Fagiano, 2020) to the drone, providing a power line communication network, flight stability (Nicotra et al., 2014), and measuring the UAV position. The tether length is adjustable with the assist of winch or spool.

Retraction system will be assigned to control the tension of the wire. The elongation of tether will be followed with the movement of the drone; therefore, a system is required to monitor and at the same time able to control the tension of the wire. For the tethered drone station, automatic spool retraction would be a suitable to be applied. There will be a modified of the spool mechanism where a sensor will be insert into as it will fully be controlled the movement of the spool regarding of the certain condition. Since the drone will travel unpredictably and the drone's height will also be adjustable, there will be a shift in the wire duration. The implementation of the automatic spool retraction would therefore be a great solution to allow the smoothness of the drone's motion while holding the wire in a tidy arrangement and reducing any disruption of the spool mechanism.

2.2 Spool and Tether

To develop a station that allow to control the tension of the taut, we need a mechanical device that able to wind up or wind out the taut. The tethered drone has a longer operation time due to the control that has been supplied through the wire associated between the drone and the ground station. The electrical cable work as the taut cable will be utilized to degree the position of the drone. An actuate winch is controlling the taut cable tension (Nicotra et al., 2017). Development of the tethered drone station counting the determination of the electrical wire. In definition, electrical wires who act as conductors will transmit power from a source to the machines.

For the most part, the common sort of electrical wire is a single-conductor wire that comes in two varieties which are stranded and solid. There are different determinations of electrical cable considering their claim characteristics in terms of its sort of fabric, gauge measure, conductors, and weight. For the reason of this paper, focus will be on the chosen criteria of the electrical wire as we need to get a clear understanding of the conduct of the wire. For illustration, we are going to take into consideration the angle of the weight of the wire, fabric sort, the AWG estimate, conductor, and conductor resistance. All these criteria will guide to make a better selection of the cable wire for the purpose of developing the tethered drone station. The electrical wire has a decisive impact on the flight capability of the drone, lower the risk of wire failure and therefore the selection of the electrical wire plays an important role (Kiribayashi et al., 2016).

2.3 Sensor system

The sensor system is one of the systems that helps to generate automatic motion without a continuous task of monitoring. One of the examples of sensors that will be used for station production is the Arduino. In general, Arduino will be programmed with a particular mission, as it will be connected to the rotation of the cable spool in our research objective. Another type of sensor that will be used in this research is the load cell. The force of that been produced from the spool will be recorded by the load cell feature. In general, the load cell or strain gauge function is to convert the electrical signal into a measurable force and has been used to determine the power, intensity, direction, and method of applying mechanical force. This device will be connected to the surface of a spring part that contracts and expands, and the data collected by the gauge will be based on the surface's mechanical changes.

2.2 Drone station frame structure

The spool, tension guard and the power station will be located at the ground station. As to ensure that the ground station stays in a position to avoid any movement during the drone being attached to this station, the first aspect to develop the drone station should be the weight. Developing a station that

can operate in any weather and time, the ground station must also be able to withstand any external interference, such as wind or water. Therefore, to satisfy the requirements, the station should be developed with material that are relatively meet half of these categories which are high density, heavyweights, anti-corrosive, and high life span material. Stainless steel will be the raw material for constructing the crucial part of ground station meanwhile an aluminum and plywood will be used for other part of the drone station. A rectangular shape of base is developed as it will be convenient for placing the other component such as spool, power station, microcontroller, and tension guard. For the fabrication of the drone station frame, the hollow bar type of stainless steel will be the main material that will be used. The dimension for the drone station frame is design through the SOLIDWORKS software.

2.3 Electric and electronics

Arduino is a circuit boards that have microcontroller chips been used for constructing and programming purpose (Badamasi, 2014). Nowadays, the Arduino is widely used in a real-life application as it can read information from input devices and send information to output devices make it been used in speakers, LCD screen and DC motor (Badamasi, 2014). The easy set-up of the Arduino setting makes it been used a lot in microcontroller programming. Arduino consist of two part which is hardware and software.

The load cell will be used in the drone station sensor system. It will be linked to the Arduino Uno board as both sensors will regulate and track the spool's rotation. By generating an electrical signal, the load cell or transducer can transform force into measurable output. In this research, a 20kg load cell module will be used as the input for the retraction system. There are four strain gauge that exist in the load cell. These strains gauge is glued to the metal block of the load cell and when the load is applied, the four-strain gauge that form a Wheatstone bridge will experience two states of condition: compress and tension. The voltage resistance that comes from the applied load at the metal block of the load cell is the value of the force that will be measure (*Circuit Journal*, accessed on 2021).

Power source is the important as to empower the drone and enable the retraction system at the ground station can be achieved. Initially, the ground base is equipped with a DC motor and therefore, it requires an electric power to generate the rotation of the motor. For this study, we will use an ac current which can be obtained from the electric generator or in-house electric power supply. The ac current will empower the ground station. The retraction system is made up of several different electrical components, including an Arduino Uno, a DC Motor, an L298N motor driver, a load cell, a liquid-crystal display (LCD), and a HX711 amplifier. The retraction system will be powered by a Li-Ion rechargeable battery with a voltage of 12V. The battery will be connected to the DC Motor and Arduino Uno which will complete the circuit for the retraction system.

2.3 Software program

The design will be develop using SolidWorks. First, the initial design of the drone station must be sketched manually, as it will assist with the SolidWorks transfer process. The sketch of the drone station will be made up of parts and assembled into a full drone station assembly in the SolidWorks. Tension guard, spool, the base of the drone station, spool handle and the power station are the portion that has been sketching and designing in SolidWorks. The preliminary result which is the design of the tethered drone station have been produced using SolidWorks software which consist of spool, load cell, DC motor and the base of the station. Next, Ultimaker Cura is an open-source 3D printer slicing application. The software enables users to plan and manage multiple print jobs across several Ultimaker 3D printers. The spool, spool holder, and DC motor basement will all be 3-D printed using this open-source software. The design will be created in Solidworks and then imported in STL format to the Ultimaker Cura. Lastly, The Arduino programming consist of C or C++ language (Verma, 2017) is essential as most of our work with the Arduino will be in the software. The Arduino software known as Integrated

Development Environment (IDE) can be downloaded from the online website Arduino.cc for free. The installation of the software will be guided completely during the installation process and once it is done, start the the Arduino Uno program by connecting to the computer via USB cable.

3. Results and Discussion

The concept of retraction system that been develop for this research is an autonomous which to allow the system works without a continuous human monitoring. As the drone is expected to have a longer flight time, tethered drone station is believed to increase the performance the functionality of the drone itself. The retraction system located at the tethered drone station that being develop is autonomous system with the installation of sensor. The load cell (strain gauge sensor) will allow the mechanical force to produce from the movement of the drone to be converted into a measurable electrical output and guide the rotation of the spool either to release or retract the tether continuously. The initial attempt of the sensory system is place at the spool. However, the data that been measurable accordingly to the force that receive from the tether less accurate as the shaft of the DC Motor already hold the spool in a fix position. To solve this issue, the load cell will be placed direct to the tension guard as shown in Figure 2 that have only one degree of freedom (x-axis direction). Thus, a more accurate measurable force produce by the tether and the drone can be obtained. For the autonomous retraction system, the load cell is the input as the value of strain produced by the tether is measured by the deformation that occurs at the metal block of the load cell. As shown in Figure 2, the 20kg load cell module is connected to the Arduino to transfer the measured force and give the signal to the DC Motor to rotate clockwise or anti-clockwise.

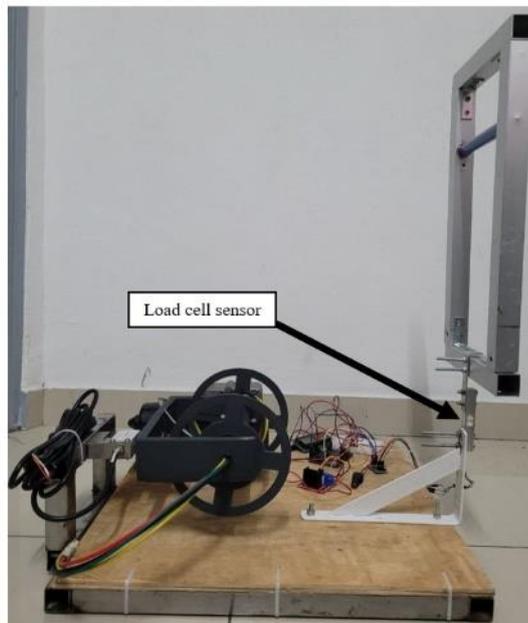


Figure 2: The position of the load cell

3.1 Mechanical evaluation

The tethered drone station will consist of power station, retraction system, and weight sensor. As the objective for this study is to identify and fabricate an automated system of retraction system, we need to consider several criteria and important equipment as to maximize the performance of the station. The drone that expected to be taut with this station produced a maximum Take-off Weight of 20 kg. The real product of tethered drone station is shown in Figure 3.

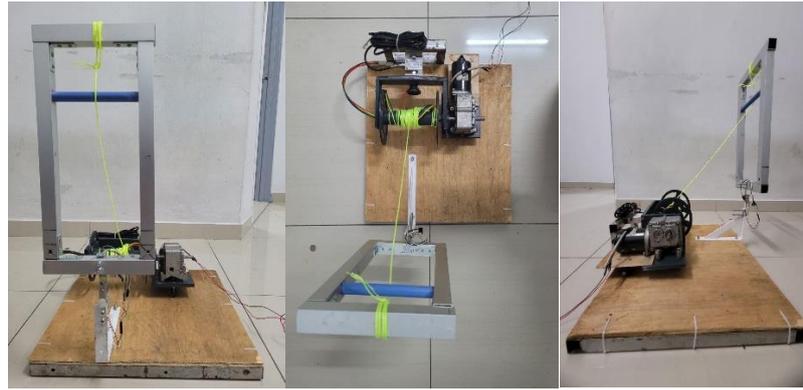


Figure 3: Prototype of Tethered Drone Station

In addition, two assumptions will be made to give a clear view on the working principle of the system. In these cases, a functionality test is conducted and the result that obtained will decide whether the selected of the design concept can be proceed to the next stage or vice versa. This assumption is made as to identify the coding of the Arduino that been applied to the system works properly and observe the behaviour of the retraction system whether it meet the desired outcome which is rotate in clockwise and anticlockwise direction.

Table 1: Functionality Test

Assumption	Expected	Result	
		Yes	No
The spool will retract the tethered wire when the load to be given is above 0.5kg	The retraction system will receive the feedback that been obtained from the load cell sensor and DC Motor will rotate in an anticlockwise direction	✓	
The spool will release the tethered wire when the load to be given is below 0.3kg	The retraction system will receive the feedback that been obtained from the load cell sensor and DC Motor will rotate in clockwise direction	✓	

Based on the functionality test as shown in Table 1, the expected result is successfully achieved. The coding of the Arduino Uno works accordingly to the desired system that been proposed. This result shows that the retraction concept that been developed is acceptable and the additional analysis of the retraction system for this study will be conducted.

3.2 Control Mechanism

The overall structure for the autonomous retraction system of the tethered drone station is display in Figure 5. The sensory system: load cell is integrated with the motor driver as to generate an automatic rotation of the DC motor. The Arduino board controls the rotational direction of the spool, and the system's coding is uploaded through the USB cable that connects the Arduino to the host computer. The system's coding is done in the Arduino IDE software, and then the code is uploaded to the Arduino board. After the coding for the load cell sensors has been created and uploaded, the output reading from the load cell will be checked to see if it is accurate. After that, create the coding for the DC motor so that it can revolve both clockwise and anti-clockwise. After the two codes fulfil the expected results, the two programs are merged into one. It was crucial in the Arduino code decoding procedure to interface the DC motor and the load cell. The DC Motor obtains data from the sensor and Arduino, which allows it to change its direction of rotation. The aim of integrating a load cell sensor into this system is to give the retraction system a boundary condition. As to enable the system to be successfully operating, a 12V battery is required to supply power to the whole system.

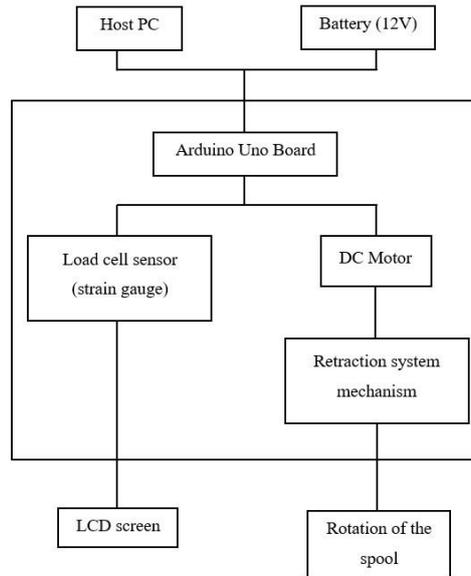


Figure 4: Overall hardware structure

3.3 Microcontroller Development

The Arduino is used to operate the retraction system of the tethered drone station. The information obtained from the system's input will be processed and given to the output. The construction of tethered drones requires Arduino code and the integration of two separate activities into a single system. The load cell, which serves as a sensor, is utilized to measure the tether's activity. The tension guard and spool at the tethered drone station are put under strain as the tether is stretched due to the movement of the drone. The load cell serves as the system's input. The strain detected by the load cell will be transferred to the DC motor, which will activate the motor's activity. The motor operates due to the existence of an H-bridge, which acts as a controller, allowing the attached DC motor to be controlled in both direction and speed without the need of a potentiometer. The L298N Motor Driver, which requires a maximum of 12V of power, is the H-bridge that has been used in this system. The motor direction is controlled by four pins: IN1, IN2, IN3, and IN4. These pins are connected to pins OUT1, OUT2, OUT3, and OUT4. Meanwhile, the pin for connecting to the power source is located at the bottom of the motor driver. The Arduino board is wired to pins IN1, IN2, and Enable A to allow the DC motor rotation to be switched automatically.

3.4 Additional analysis

As to build an automatic retraction system, we conduct three testing to verify the proposed concept. In this case, there are three items that we focus on, which are the tension produced by the tether, the load cell feedback, and the movement of the shaft at the dc motor. The manipulated variable for this testing is the force produced by the tether. A different mass values is used of which can be assumed as the force produced by the drone itself. Based on the coding of the Arduino, it will respond to the load and signal to the retraction system to start to operate. In this validation testing, we will assume that there is no external disturbance as the objective is to verify the system and the coding that we develop is successful.

The following assumption were used in this investigation.

1. It is assumed that when the retraction force is at or lower than upper pre-set threshold, it indicates the wire is in loosen mode. Thus, the retraction process is activated, and the DC Motor will rotate in clockwise direction to wind in the tether.
2. Stable condition is defined as the condition where the load in the range of 50g from the upper threshold. **Error! Reference source not found.** shows the experiment that been conducted to verify the functionality of the retraction system for release condition with sets of pre-set thresholds.

Table 2: Retract condition

Run	Pre-set threshold (g)	Expected of operation mode (DC Motor)	Actual threshold (g)	Actual of operation mode (DC Motor)	Threshold differences	Errors percentage (%)
1	50	Retract	52	Retract	2	4.00
2	100	Retract	104	Retract	4	4.00
3	150	Retract	147	Retract	3	2.00
4	200	Retract	193	Retract	7	3.50
5	250	Retract	250	Retract	0	0.00
6	300	Retract	305	Retract	5	1.67
7	350	Retract	348	Retract	2	0.57
8	400	Retract	405	Retract	5	1.25
9	450	Retract	454	Retract	4	0.89
10	500	Retract	503	Retract	3	0.60

3. It is assumed that when the retraction force is at or higher than the upper pre-set threshold, it indicates the wire is in stretching mode. Thus, the release process is activated, and the DC Motor will rotate in anti-clockwise direction to wind out the tether.
4. Stable condition (no rotation of DC motor) is defined as the condition where the load in the range of 50g from the upper threshold. **Error! Reference source not found.** shows the experiment that been conducted to verify the functionality of the retraction system for release condition with sets of pre-set thresholds.

Table 3: Release condition

Run	Pre-set threshold (g)	Expected of operation mode (DC Motor)	Actual threshold (g)	Actual of operation mode (DC Motor)	Threshold differences	Errors percentage (%)
1	150	Release	155	Release	5	3.33
2	200	Release	200	Release	0	0.00
3	250	Release	253	Release	3	1.20
4	300	Release	307	Release	7	2.33
5	350	Release	352	Release	2	0.57
6	400	Release	401	Release	1	0.25
7	450	Release	455	Release	5	1.11
8	500	Release	500	Release	0	0.00
9	550	Release	553	Release	3	0.55
10	600	Release	608	Release	8	1.33

After the testing is conducted, the observed data which is the actual threshold and later will be compared with the pre-set threshold that been clarified in the Arduino coding. The value of threshold differences is calculated by subtracting the value of the pre-set threshold to actual threshold. The

difference of threshold occurs due to the calibration in the Arduino coding. The expected operation mode of DC Motor indicates that the system is operating according to the assumptions given for both retract and release condition. Thus, the retraction system that been develop has meet the expectation condition.

4. Conclusion

The integrating between the load cell which play the role of sensor and Arduino Uno has successfully develop a microcontroller system for the station. The input that been used for the system is the strain value measured by the load cell which then is transfer to the Arduino that will process the data and command the DC motor to start rotating. The retraction system uses a load cell sensor that is connected to a microcontroller (Arduino Uno) via a HX711 amplifier, and the data will be sent to the system's output, which is a DC motor driven by an L298N motor driver. With a 12V power source, the DC Motor has a rotation per minute (rpm) of 6. The final evaluation of the developed robot found that the design has fulfilled the expected pre-defined performance. The autonomous retraction system was found able to react following the requirement. Based on the experiment result, the operation mode of the DC motor was stable and functioning well. The relationship between the theoretical and actual control systems was determined by the experimental method. A functionality test is conducted at the earlier stage. Next, the additional analysis is performed to identify the system that has been developed is available to works at the different condition and evaluate the percentage error that exist. Based on the result obtained from the additional test, the accuracy for the developed system both in retraction and release condition has an average errors percentage of 1.85 and 1.07, respectively.

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