Flipping Mechanism Design for Overturned Drones

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***Abstract*—The overturning of a drone causes personal losses and disturbances in residential communities. In general, unmanned aerial vehicles fly beyond the range that humans can reach in the sky. Recovering a drone from a fall is not easy. The conversion of a fuselage into a reasonable angle and using a propeller to operate lift are beneficial. The use of a flipping mechanism can eliminate such problems with overweight control. A rotatable arm mechanism was used to change the fuselage angle for obtaining an improved take-off posture through multiple attempts. The design process included concept drawing, functional element survey, functional simulation using a simplified model, and an environment scenario practice in determining appropriate design parameters. The chassis rotates beyond the vertical line when the arm is sufficiently long. A prototype model was constructed using an Arduino platform to integrate mechanical and electronic parts. Protection frames were added in the second prototype to improve stiffness.**

***Index Terms*—flipping, drones, mechanism design, Arduino**

I. Introduction

Drones are robots that fly in confined spaces. Drones can be classified based on different parameters [1], including styles of flying (e.g., perpendicular motion, roll, yaw, front and back, and sideways movement). They are used for various purposes, including entertainment, education, and performing official duties, and have multiple benefits in applications such as surveillance, patrolling protection, and aerology.

Molodchik [2] classified drones based on their weight and range as follows: micro, mini, and large. Based on flight range, drones classified as close-range, lightweight small-range, lightweight medium-range, average-range, medium-heavy-range, heavy-medium-range, and high-endurance unmanned aerial vehicles (UAVs).

A. Problem

Drones have been used in the collection of water samples [3]. It uses global positioning system navigation or remote control to fly to a destination and to hover above the water surface. It uses weight and buoyancy to change the angle and orientation of the water-sampling cup to collect water samples near a pollution source. The drone is affected by terrains, or propeller rotation is interrupted by objects, and thus, sometimes, it falls and turns upside down [4]. The drone encounters difficulty in overcoming this problem.

Many drones used for aerial photography fall on the ground because of battery drainage, resulting in personal losses and disturbances in residential communities, thus endangering public safety [5]. The drone prices range from U$100 to U$4000. An unreachable drone causes a financial loss to the owner. Besides, information on the drone memory is essential, and the owner anticipates the retrieval of information.

B. Methods of Escape

Ejecting module retains crucial components. An in-flight monitoring drone responds to power failures on a drone electrical system. The system emits the instrument package and initiates the transmission of homing beacon signals [5]. The servo system controls the glide path during payload landing. In a previous study, a servo system adjusted the length of control lines attached to the parachute for the parafoil recovery of UAVs [6].

When the main body falls on the ground, the drone cannot take off, possibly because of the surrounding hindrances. It can take off if the body is bounced from the trapped environment by using a preconfigured spring. Some animals or robots can achieve a similar task. For example, a diameter of 12 cm jumping robot can overcome obstacles of 76 cm [7]. The Galago uses a power modulating strategy to obtain high peak power.

Another leg mechanism enables a jumping robot to achieve vertical jumping agility of 78% [8]. The low ground friction also helps to flip the robot body [9] to overcome torque limitations of its actuators. The design geometry allows equilibration in an upright orientation with a hop-and-roll movement. Moreover, combustion-actuated soft robot uses chemical reaction energy applied to the bounce equipment [10].

II. Method of Design

Drones use built-in microcontrollers to control the motors. Flipping occurring after a fall is related to the change in posture. To reduce the complexity, a simple rotation mechanism, which uses residual power to recover drones, was used in this study. The actuator design changes orientation, and thus, the drone can retain its normal state and increase return probability.

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A. *Design Process*

During the design process, the designer must repeatedly consider possible situations and parameters and select appropriate settings to reduce the time spent on erroneous attempts. Fig. 1 shows the design flow. The procedures were: 1) Available components of the related function were considered. 2) Technical characteristics were observed through a simplified model. 3) Appropriate parameters were determined using simulations. 4) The design group provided several concept drawings. 5) The main structure was configured using screened parts. 6) A prototype was constructed using 3D printing to evaluate the structure status and possible pitfalls. 7) The prototype was adjusted and redesigned to improve the performance of the system based on evaluations.

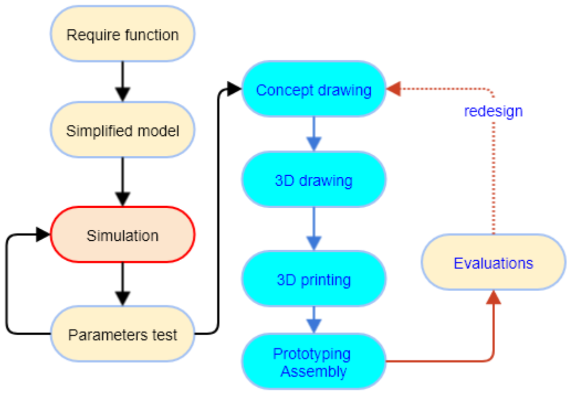


Figure 1. Design flowchart

B. *Rollover Simulation*

When performing the rollover, a support foot is required to change the fuselage angle. The device must have a low weight and must not significantly increase the flight load. A simple rotating arm was used for reducing the complexity of extra components (Fig. 2). The length of the support rod is critical to ensure rollover. When the fulcrum position is away from the center of gravity, the chassis can roll over in a reasonable time.

The drone body is a complex three-dimensional structure. The structure was simplified into a two-dimensional uniform mass distribution model for understanding the design parameters. The simplified model was analyzed using Working Model 2D.

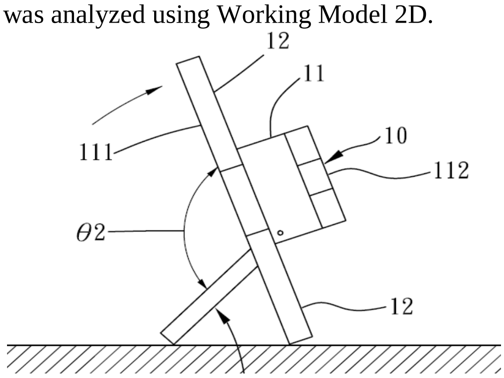


Figure 2. Schematic diagram of the rotate rod [11], where Θ2 is the rotation angle

The arm length must be sufficient for a successful flip. The initial state of the body (Fig. 3) is upside down, and the drone gradually rises when the motor rotates. However, after reaching the maximum angle, the arm length is insufficient, and thus, it falls back to the original state. Fig. 4 is in the same starting state because of the appropriate arm length. Therefore, the motor rotates beyond the vertical line and successfully returns to the normal state.

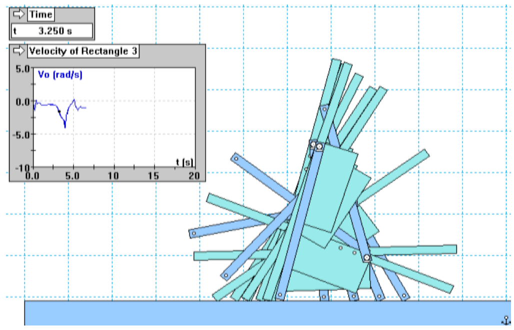


Figure 3. Failure of rollover (the arm length is 3.8) the arm reached the max angle at t=3.25 sec.

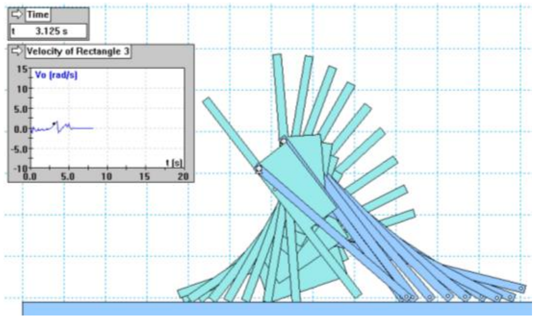


Figure 4. Rollover at t=2.75 sec, where the arm length is 4.8 unit

Fig. 5 shows the relationship between the time required to attain the maximum upright angle and length of the arm. The arm length is directly proportional to its speed of reaching above the vertical line. Although the increasing arm length can increase the speed of the flip, it increases weight and dimensions. Therefore, appropriate design parameters must be selected based on the requirements and overall considerations. In a drone body, mass distribution is not uniform, and the main body chassis is considerably smaller than the four rotating propellers. The total mass of the tested drone is 207 g. The diagonal distance between propellers is 27 cm (propeller radius is 7 cm). After evaluation, the length of the rotation arm was selected to be 20.6 cm.

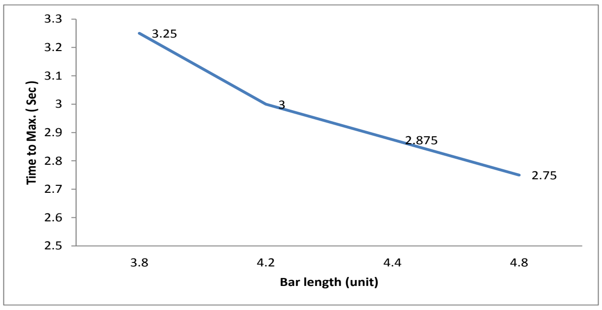
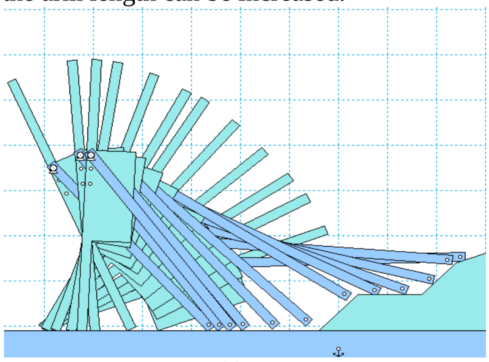


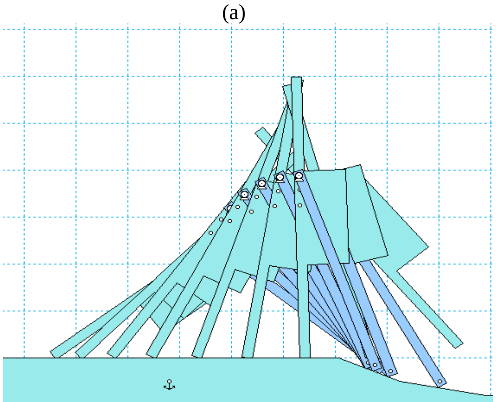
Figure 5. The time to max angle changes with the length of the bar (shaft position on side)

C. Nonflat Surface

In a real environment, the location of the drone drop is generally not flat, with hindrances such as plants around it. Fig. 6(a) and (b) show the flipping process in a convex or concave topography. The results are slightly different from those of flat terrain with uneven mass distribution. Hence, the arm length can be increased.



(a)



(b)

Figure 6. Rollover on (a) bump surface at t=2.75 sec, where the arm length is 4.8 unit; (b) on the concave surface at t=3.00 sec, where the arm length is 4.5 unit

III. Material and Concept Design

According to the simulation results, several design concepts can be explored through brainstorming. Fig. 7 shows a sketch of a rebound rollover mechanism with a circular frame placed on each propeller as a protector. It is an annular thin shell structure attached to the surface of the main body casing at ordinary time, and it provides a turning effect by rotating the motor when required. The advantage of the shell structure is that the overall structural strength is increased because of the arching fact.

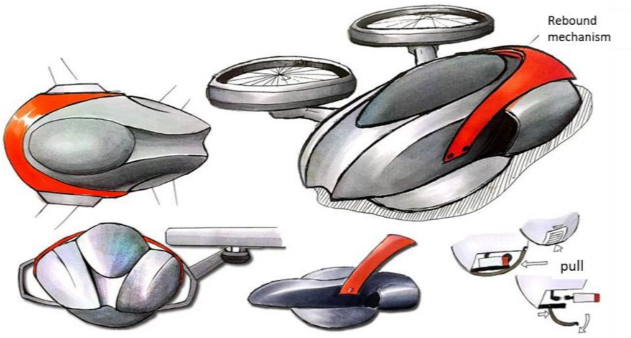


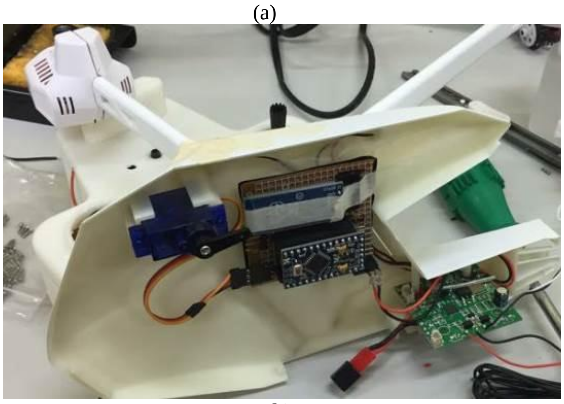
Figure 7. Idea sketch

A. Prototyping

During prototyping, a designer must consider all parts (i.e., a chassis, motor, and controller) and organize them to demonstrate primary functions. The selected electronic control module is Arduino-mini pro [12, 13] with a Bluetooth module and a servo motor shield. A lithium battery was placed in a low position. The motor shield was selected based on market availability [14]. Brushless DC (BLDC) motor drive systems are generally used in robotics, actuators, and manipulators with high efficiency and weight to torque ratio [15]. A high-torque and low-speed motor were used to match our application.

Fig. 8 shows that users start the rebound mechanism circuit by sending a signal from a remote controller. A Bluetooth transmitter operated using a 2.4G signal was used for prototyping. The Bluetooth module has a transmission distance of 10 m, and in the real world, a long-distance transmission module is required for remote control. The current size of the Arduino module and rebound mechanism makes the main chassis larger than an ordinary commercial product. However, the control chassis can reduce the volume in the future. The main body was manufactured using 3D printing with polylactic acid (PLA) material. Four propeller fulcrums and swivel arms are made of carbon fiber pipes to reduce the weight.

(a)



(b)

Figure 8. The servo-driven lever: (a) overall form, (b) Arduino circuit board.

IV. Results and Discussion

The servo-driven lever turns the body back to the normal state. An Arduino circuit board includes a mainboard, a servo control, a Bluetooth module, and an orientation sensor. The circuit function and pitfalls in this prototype were evaluated.

A. Evaluation

Protection frames are not present around the propeller in the prototype. Sometimes the drone fails to turn (Fig. 9). The position of the spiral blade affects flipping efficiency. A force applied in the opposite direction when the blade touches the ground can cause a reverse rotation. The two helical blades can withstand the supporting force when they are in contact with the ground. The uncertainty of the dwell angle of the blade reduces the possibility of a successful turnover.

Circular frames were added to each propeller in the second prototype. The circular frame outside the blade has stiffness, which supports the force during rotation. This stable structure helps the successful completion of the flip. Fig. 10 shows that the favorable situation enhanced, and the rebound angle maintains in the same range. The ring increases the weight, and thus, using a low-density material and removing unnecessary parts are essential.

Figure 9. Propeller without protection ring: sometimes it turned successfully.

Figure 10. Propeller with protection ring: completed flip

B. Redesign

Fig. 11 shows one of the redesign ideas. A circuit ring was employed outside to enhance the structural strength. A covered structure (#12) on the outer edge of the blade prevents possible damage. A support shaft (#P1) was placed at the one end of the body chassis with a fulcrum near one side of the body (#212) for turning. The user could send a signal (#S) to activate the servo motor (#22) remotely.

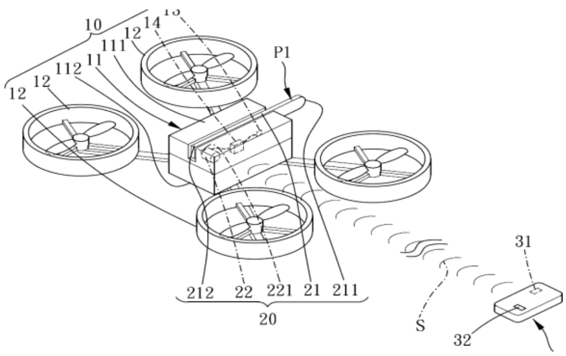


Figure 11. The redesigned model: added covering ring [11]

The rectangular box (#11) in the middle comprised a small control circuit and battery, and the shaft was at the side of the servo motor. It was installed not at the center but on one side, and thus, the arm length (#P1) and the benefit of the flip could be increased when rotating. The motor is massive, and therefore, the center of mass is approximately at the lower side of the square box on the motor area. When the arm rotates, the frame becomes a support point (#12), and the motor torque moves the body in the opposite direction.

The evaluation indicates that if the motor continuously rotates, the drone may attain the dumped state again. The redesigned model must be equipped with an orientation sensor to avoid such a situation. When the body is upside down, the motor is activated through human manipulation (#32), and the arm rotates until the body is back to the normal position (Fig. 12). At this point, the circuit immediately stops motor rotation, and the user controls the drone to continue flying.

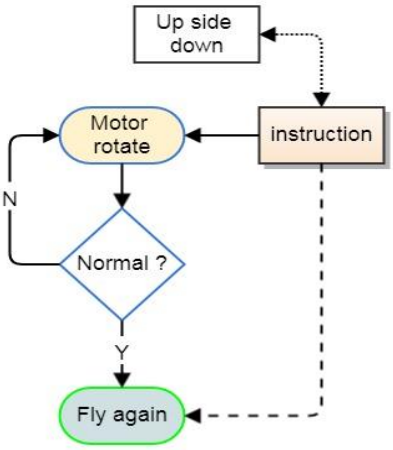


Figure 12. Flow chart of attitude sensor and motor control

V. CONCLUSION

The overturning of a drone causes personal losses and disturbances in residential communities. The conversion of a fuselage into a reasonable angle and using a propeller to operate lift are beneficial. The flipping mechanism can overcome such problems. When the arm is sufficient, the motor can rotate beyond the vertical line and successfully overturn. The arm length is positively correlated with the speed of the flip. However, the increasing arm length increases weight and dimensions.

The design process used a simplified model to determine appropriate design parameters. The prototype was constructed through the integration of mechanical and electronic parts. Two prototype models were developed to verify the functions of the model. Protection frames were added around each propeller to improve the turnover and to change the drone position for take-off. The current size of an Arduino module and rebound mechanism is larger than the commercial product. The size and weight can be reduced using built-in sensors and circuit miniaturization.

Conflict of Interest

The authors declare no conflict of interest.

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