ZMART Technical Report

The International Aerial Robotics Competition 2014

ZJU's **M**icro-**A**erial **R**obotics **T**eam (**ZMART**) [1]

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Abstract

The Zhejiang University Micro-Aerial Robotics Team (ZMART) has prepared to participate the 2014 International Aerial Robotics Competition (IARC). Our team aims to demonstrate interaction with one moving object while autonomously navigating in an sterile open environment. The basic system structure consists of a quadrotor helicopter platform, micro processor, control units, different kinds of sensors, communication module, a RC controller and a base station. The hardware structure, as well as the algorithm structure, will be introduced in this report.

Keywords:
Quadrotor Helicopter, TLD Vision Algorithm, Inertial Measurement Unit based Localization, Potential Field Method

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1. Introduction

Since the intent of the International Aerial Robotics Competition (IARC) is to encourage new technology development of aerial robotics, Mission 7 tests participants with interaction with moving robots and navigation without external supports. This mission requires the unmanned aerial vehicle (UAV) to herd ground robots to one side of arena, avoid obstacles, keep height within limitation and compete with other aerial vehicles in the second part of the mission. Compared with former missions, Mission 7 diminishes the importance of simultaneous localization and mapping (SLAM), so new method is demanded.

The key factors of this mission are moving object tracking, high-speed control and strategy. In our solution, once the moving object is captured correctly by the camera, the velocity of target is equivalent to the UAV's. By calculating the UAV's velocity orientation we can make the decision whether interaction is needed or not. All processes happen in milliseconds and new control signal may come to the actuator before UAV reach stable, so a quick control algorithm is necessary. Since there are multiple targets, target robot should be selected first. After looking on to a specific target, the UAV can process into tracking or interaction operation.

Since it is the first time for our team to take part in this type of competition, all work must be done by our groups without any previous experience and hardware setup. Our yearly milestone is to herd one ground robot to the appointed side of arena. By now, we finished

[1] **Team Leaders**: Tao Han, Jiangcheng Zhu (Overall; Flight Control), **Members**: Tong Qin, Endong Liu (Localization), Haoyu Liu, Quanquan Zhang (Obstacle Avoidance; Communication), Zhongkai Lu, Changchun Ye (Vision), Xingsuo Liu (Height Control;Airframe Design), Zhonglei Wang (System Integration) and Changxu Lou (Airframe Design); **Supervisors**: Chao Xu, Lei Xie

building our own UAV system, implementing the vision searching algorithm, the localization method. We anticipate for an attempt in this coming August.

2. Aerial Vehicle

A quadrotor, or quadrotor helicopter, is an aircraft that becomes airborne due to the lift force provided by four rotors usually mounted in cross configuration. Quadrotor helicopter has all the blades fixed to the axles, and achieves flight control via collaboration of the propellers.

We choose quadrotor helicopter as the flight platform. A quadrotor helicopter has four propellers, which could provide more lift force than a classical helicopter in similar size. Also, as all the axes of the propellers are parallel and fixed, the physical construction is relatively simple and more robust than many other structures. The space within the four propellers is a suitable place to set onboard electronic system on the geometrical center of the quadrotor helicopter. This regular layout reduces the computation complexity of localization and obstacle avoidance.

Figure 1: The Quadrotor Platform

2.1. Airframe

The airframe is the mechanical structure of an aircraft that supports all the components. Designing an airframe involves important concepts and knowledge of applied mechanics, aerodynamics, materials engineering and manufacturing technologies to achieve a good performance. Fortunately, since the quadrotor has become a popular one in the aero-modeling field, there are many standard components for us to form them up.

Concerning the competition background and assigned task, we choose the airframe in Figure 1, which has a raw diameter of 650mm. The airframe is made of carbon fiber and engineering nylon. This kind of airframe compromises weight and mechanical strength quite well.

As there are many electronic boards and sensors, such as laser scanner and camera, to be installed on the airframe, we use nylon plastic boards and nylon support shores to extend the installation plates.

2.2. Propulsion System

The motors we used in this project are electric Direct Current (DC) motors, which are lighter than combustion engines and independent of combustible fuel. Furthermore, brushless DC motors performs more efficiently to be worthy of their cost, when compared to brushed DC motors.

To control the speed of a DC brushless motor, Electronic Speed Controller (ESC) must be used. This hardware receives the power supply from the battery and drives it to the motor in a specific phase consequence according to a Pulse-Width Modulation (PWM) signal that is provided by the controller unit.

The DC Brushless motor, Electronic Speed Controller and EPP-1245 propeller form the propulsion system. This efficient and dependable combination is all based on the experiences from the attempts of many aero-modeling DIY players. With sufficient power support, this propulsion system could provide lift force of about 3kg in maximum.

2.3. Power System

In the aero-modelling market, electric batteries have proven to be a long term cheaper solution compared to combustion engines. Though combustion engine provide far larger lift force and duration time, it is too heavy to such a quadrotor helicopter. A light and robust power source, Lithium Polymer (LiPo) battery, a newly developed power storage technology, is being called as the best choice of quadrotor UAV system for its high capacity.

A 5100mAh LiPo battery supports all the electric cost of the UAV system. The 4 ESCs obtain 11.1V electric power directly from its polar. Electronic board and sensors get 5V electric power from the ESC. Four motors work in power of 400W, when hovering. Thus, the regular working time of the quadrotor flight platform is about 10 minutes.

3. Hardware Structure

The hardware system includes two parts, the onboard system and the base station. The onboard system consists a Central Control Unit (CCU), a micro processor, an Inertial Measure Unit (IMU), a 2D laser scanner, two cameras, a RC controller and a communication module. The base station is a laptop computer.

Those hardware works in two frequencies according to various demands. The control unit, laser scanner, cameras and IMU must work in a comparably high frequency because all events like obstacle avoidance and target tracking can happen at the same time and all functional modules should operate at same high frequency. The communication with base station should also be kept at this high frequency to ensure prompt data visualization. The communication with RC controller, or the safety assurance module works in a relatively low frequency.

3.1. Control System

There is only one level of control system on the UAV, the flight control unit. It is in the CCU, the WooKong control board. This unit is responsible for operating the commands from top level. Because of the application of RC controller, between the top level and bottom level there is a autonoumous/manual control switch. The switch can communicate with the the RC

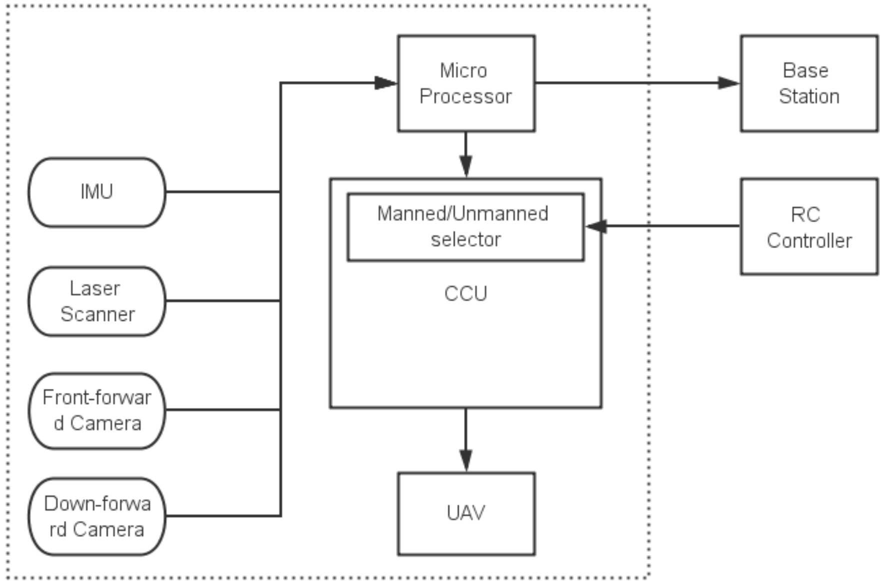

Figure 2: The Hardware Structure Diagram

controller and when necessary, it can be used to control the UAV manually. This switch is integrated into the CCU.

The top level is an onboard micro processor and responds for collecting data from sensors, processing information, generating control command and sending data to base station.

3.2. Inertial Measurement Unit

An Inertial Measurement Unit (IMU) is an electronic device that measures the velocity, orientation and gravitational forces of the aerial vehicle simultaneously, using a combination of accelerometers and gyroscopes, sometimes magnetometers. The IMU is the main component of inertial navigation systems used in various aerial vehicles.

The 3-axes accelerator and 3-axes gyro are integrated in the WooKong control board. This IMU is relatively light but lower-quality. Another attitude measurement unit is the electronic compass. All data is exacted from IMU module and used for localization.

A major disadvantage of using the IMU for navigation is that they typically suffer from accumulated errors. Because of its low quality, we use these lines on arena to validate position. So for localization both of IMU and vision system are used.

3.3. 2D Laser Scanner

A laser scanner is a device which uses a laser beam to determine the distance to an object. By sending a narrow-beam laser pulse, the distance to the object could be computed from the time between the sending and returning of that pulse.

Concerning the scan range and weight, the Hokuyo UTM-30LX 2D Laser Scanner is chosen. URM-30LX is a laser sensor for area scanning. The light source of the sensor is infrared laser of wavelength 785nm with laser class 1 safety. Area can be scanned is the sector with maximum radius of 30m and sight of 270 degree. Its gross weight is 270g, far lighter than the commonly used SICK Laser Scanner on ground robots.

Hokuyo 2D Laser Scanner could get the obstacles' position in polar coordinates. It returns its measurements in an integer array of the size of 1080. From 0 to 270 degree, the beam scans counter-clockwise at a step of 0.25 degree. The data can be input into the obstacle avoidance module.

Besides the application in obstacle avoidance, we can use a little right angle prism to reflect part of the beam onto the ground to measure height. The information of height is used in height control and decision of interaction.

3.4. Vision System

In this UAV system, two cameras will be installed onboard, one for forward-sight, another for down-sight. This kind of camera has power supply independent from aircraft main power system, which could support about 1 hour work time in regular. Video taken by cameras will be processed firstly by the top level micro processor.

The wireless camera for forward-sight is used in searching mode. After the UAV launches, forward-sight camera searches ground robots and leads the UAV to approach target until the ground robot enter the scope of down-sight camera. The one for down-sight is used to tracking the target robot and keeping the target robot in the center of camera coordinate.

3.5. Communication System and Base Station

A wireless communication module is used to transmit data between top level micro processor and base station. This Wi-Fi communication module could guarantee an efficient and dependable data interaction between the onboard system and the base station.

According to the amount of data, Wi-Fi method can provide a channel that is fast enough. All algorithms are running on the onboard processor and the only task for base station is data visualization. Through visible data we can check the operation state of UAV. We can transmit to manual control mode instantly when we find the UAV does not function well.

3.6. Safety Assurance

According to the safety requirement, we design a autonoumous/manual control switch and integrate it into CCU. It can receive signal from the RC controller. The switch is independent of both top and bottol level processors. Once the RC controller emits particular signal, operator can take over the control of UAV. When there is need for manual control, for example, the UAV can not operating independently, this module can ensure safety. Our operator outside of the arena will follow the UAV so that the UAV is kept within the effective range.

4. Software Structure

Briefly, the software structure of the UAV system could be divided into four functional part, localization, tracking, height control and obstacle avoidance. Final result in every loop is the fusion of all modules. Different combination of modules is used in different modes. We develop our software structure in Robot Operation System (ROS). This open source platform provides various packages that can be directly integrated into our system.

Though the whole software structure could be divided into four parts clearly, they are not always corresponding to a certain hardware or algorithm. For example, the down-sight camera provides information for position validation and also provide data for object tracking.

In this section, algorithms of all modules will be introduced. The structure described below is operated in herding mode. The structure operated in herding mode will be illustrated specifically.

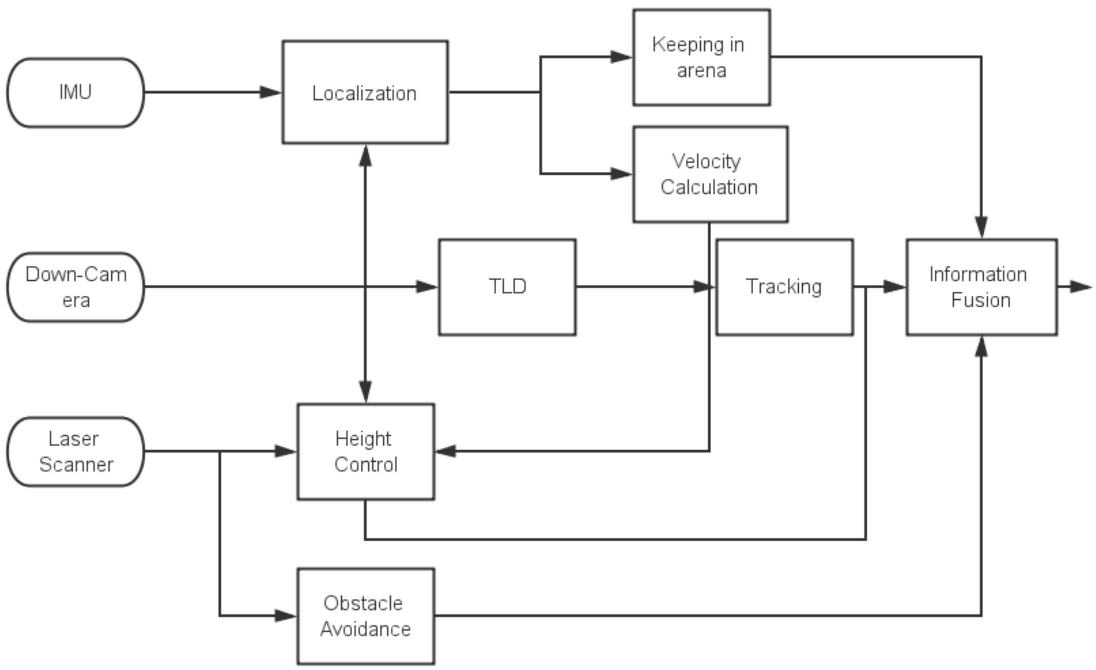

Figure 3: The Software Structure in Herding Mode

4.1. Mode Determination and Searching Mode

There are two mode in our system, herding mode and searching mode. The most important information for mode switching is whether there is ground robot in the visual field of down-sight camera. If there is no target in down-sight scope, the system will be kept in searching mode, otherwise in herding mode.

In the searching mode, the top priority is to find target and hover over it. Once the target enter the scope of down-sight camera, searching mode is finished and herding mode structure described above will be operated.

In the searching mode we use the forward-sight camera to achieve a wide scope. When the target is found, the UAV will approach the ground robot. As long as UAV is close enough, the ground robot will appear in the coordinate of down-sight camera and then herding mode begins.

4.2. Vision

TLD is a real-time algorithm for tracking of unknown objects in video streams. It is developed by Zdenek Kalal, a Czechish student in University of Surrey. TLD means tracking, learning and detecting. This method simultaneously tracks the object, learns its appearance and detects it whenever it appears in the video. With this method, the computation system could track almost every moving thing in its visual field [K$^+$09].

In our system, TLD method is enriched. We try to maintain the ground robot in the center of down-sight camera visual field. TLD method in our system is not only a moving object tracking system but also a controller. This controller output is used to adjust position of UAV and make the UAV follow the target. By making UAV follow the target, we link the velocity of target to the velocity of UAV. These two velocities are equivalent and through localization module the velocity of target can be extracted easily.

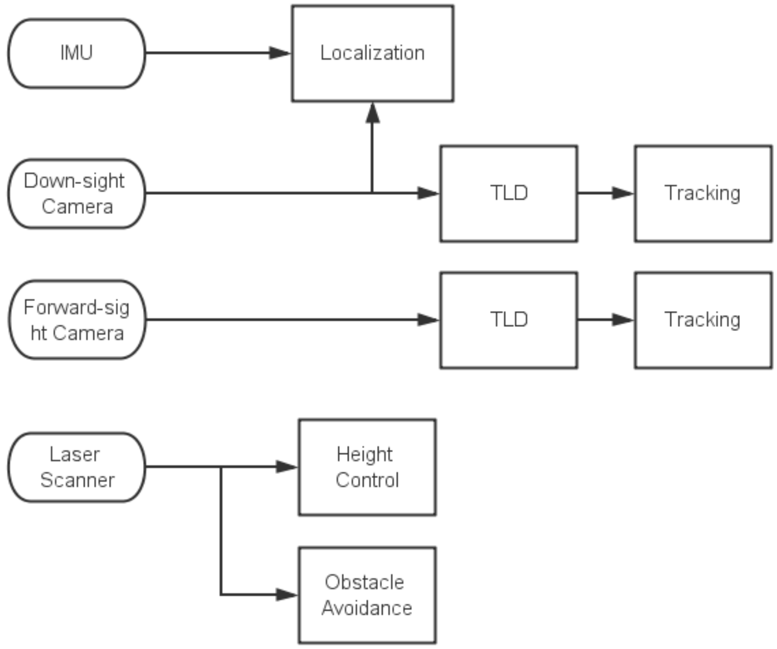

Figure 4: The Software Structure in Searching Mode

In the TLD method, Zdenek use an online learning method to get the feature of the target. Regardless of rotation and tilt, it works well. We will add an off-line learning part before the UAV takes off. The UAV will get features about the ground robot. Specially, the forward-sight camera is trained with side-looking images of target while the down-sight camera with down-looking images.

By now, we implement this TLD method with OpneCV and C++. We just use its free version to accomplish the mission in this non-profit competition.

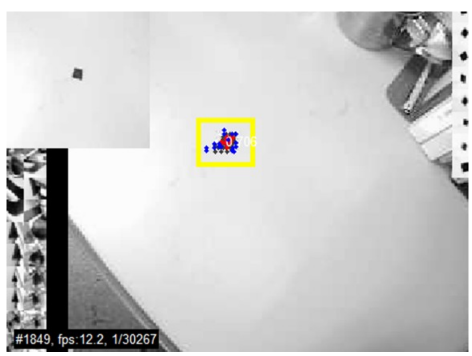

Figure 5: Using the TLD Method to Track a Chip

4.3. Localization

In this mission, a prior map can be built into micro processor, so the pressure for localization is not main concern. Compared with former missions, accuracy requirement is not strict so the computational load is relatively low. The purposes of localization are keeping the UAV remain in the arena and computing the velocity orientation for decision making.

The foundation of localization algorithm is an odometer. The data from IMU and electronic compass are processed by the odometer. Based on the prior map, the odometer can provide basic position information. However, the quality of odometer is not high enough to provide reliable position and validation should be applied. We use the lines on the arena as landmark to implement validation. Due to the linear feature, simple edge extraction is adequate.

Position information is used to prevent the UAV from crossing the boundary. Another application of localization information is to compute the velocity orientation of ground robot. This orientation is the key factor for deciding whether interaction with target is necessary.

4.4. Height Control

There are two tasks for height control module. The first one is measuring the height. Since mission 7 has a limitation for flying height, the height control module needs to keep the UAV below the limitation. In our system, height control module will keep the UAV at a certain height. The height will change only when it is necessary to interact with ground target.

Another task for height control is to execute the interaction command. When the orientation from localization module is incorrect, which means the target is heading wrong direction, the height control module will make the UAV descend, keep at a low height for completion of interaction, then ascend to normal height again.

Here is a challenge for height measure. Since the height from laser scanner is relative height and there is target robot on ground, we need to identify whether the height information is between ground and UAV. We use information down-sight camera as verification. The scanning scope of laser scanner is fixed in down-sight camera, so we could use result from TLD module to determine whether there is a robot in scanning scope.

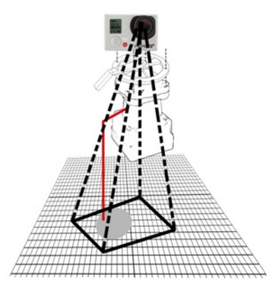

Figure 6: Measure the Height

4.5. Obstacle Avoidance

There are already many methods proposed for obstacle avoidance. Artificial potential field approach is a real-time robot path planning method, and is widely used for autonomous mobile robot obstacle avoidance due to its elegant mathematical analysis and simplicity. Combined with the detection data from laser scanner, artificial potential field approach can determine admissible and reachable place for its path planning [Kha85].

Compared with method like dynamic window approach, potential field method is more effective and simple for our task due to there are just 4 robots with tall cylinders obstruct the aerial robot.

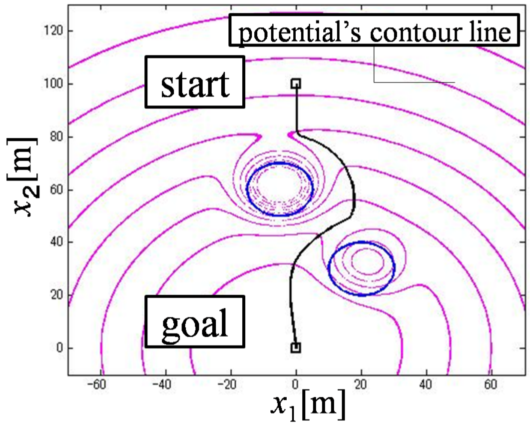

Figure 7: Potential Field Method

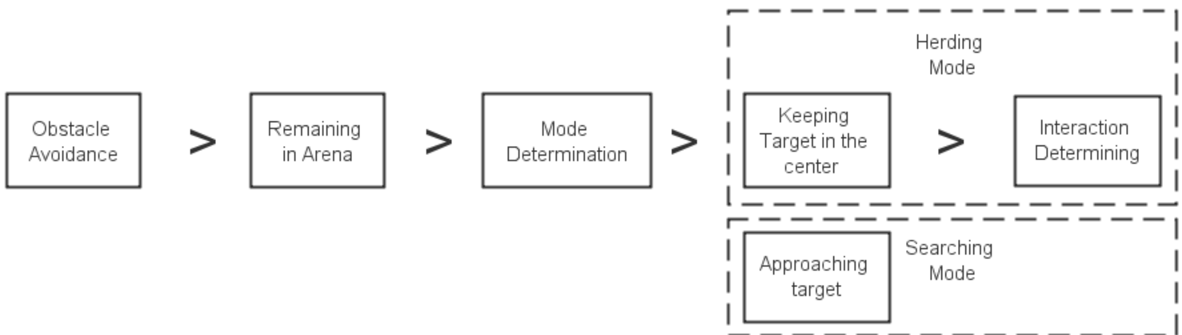

Figure 8: Priority of Events

4.6. Information Fusion

All four information will contribute to final result in every loop but the priority of events is different. We design the process of information fusion according to the importance of events.

The obstacle avoidance is the top priority. Although flying height is limited in this mission, our UAV only have two kinds of height: high level for normal operation and low level for interaction with ground robot. Thus, we do not need to pay special attention to restrict flying height. Prevent the UAV from crossing the boundary is the secondly most important. Mode determination follows. Then we need to make sure that the ground robot is in the center of camera visual field. At last, the velocity orientation from localization module is applied to determine whether interaction is needed. In searching mode, event in the lowest priority is to approach target in forward-sight camera.

Information fusion in every loop can be illustrated as figure 9, 10, 11.

5. Conclusion

In this work, we develop an UAV system, based on a quadrotor platform, for the IARC Mission 7. Four main modules, localization, obstacle avoidance, height control and object tracking are implemented in both hardware and software. Although this system is designed

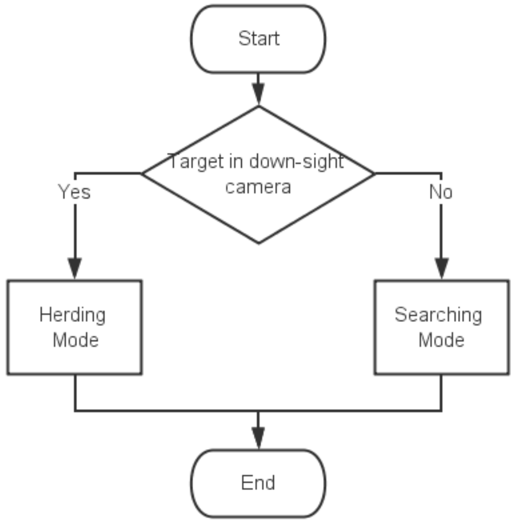

Figure 9: Process of Information Fusion

for one ground robot, the system can be modified for the completed mission after adding strategy module which is used for target selection. Additional test is still needed before the UAV system become robust enough.

Acknowledgement

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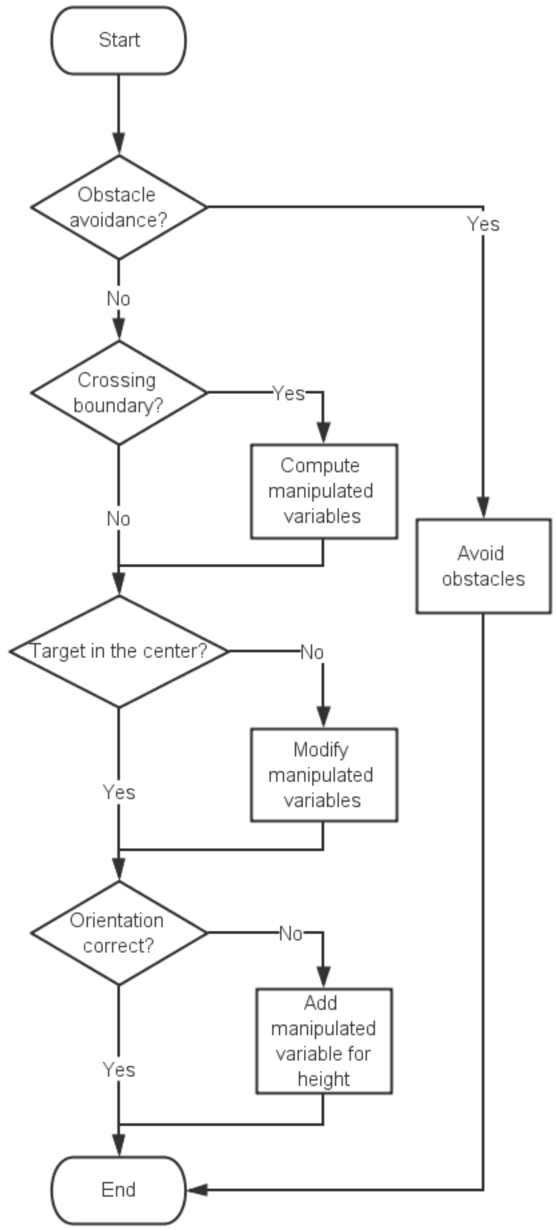

Figure 10: Subprocess of Information Fusion in Herding Mode

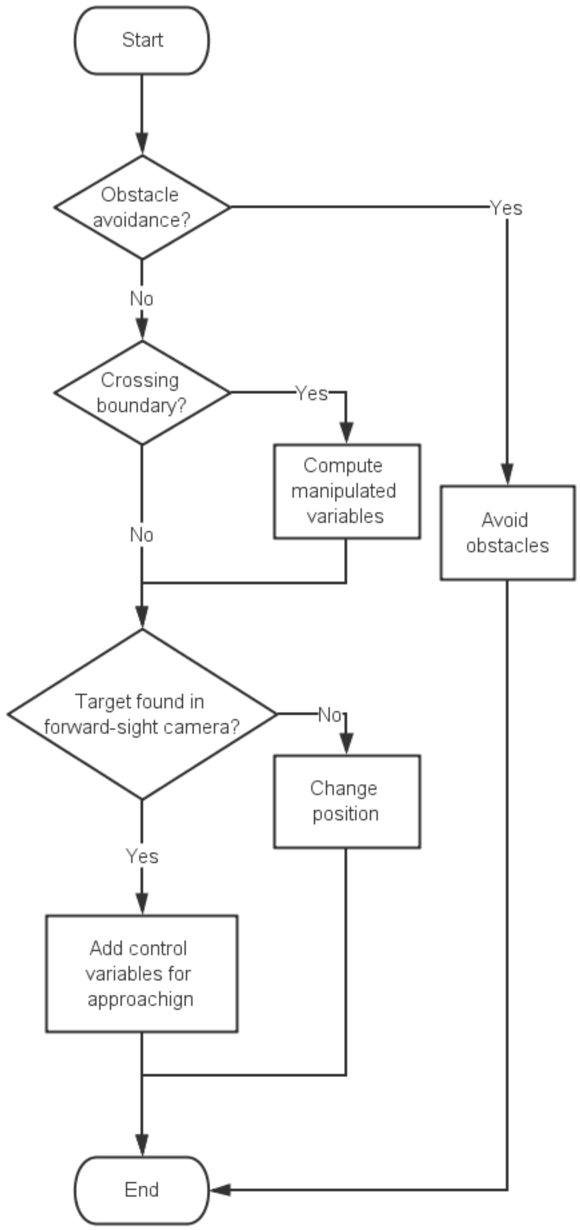

Figure 11: Process of Information Fusion