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POSITION CONTROL FOR AUTOMATIC LANDING OF UAV IN A NET ON SHIP

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Abstract

Automatic landing of a fixed wing Unmanned Aerial Vehicle (UAV) in a net on a ship require an accurate positioning system. There exist today high-end systems with such capability for special applications, e.g military systems and costly commercial systems, which restrict the availability of such systems. To increase the general availability these systems must consist of low-cost components. Here, an alternative is the use of low-cost Global Navigation Satellite System (GNSS) receivers and apply Real Time Kinematic GPS (RTK-GPS), which can provide centimeter level position accuracy. However the processing time for the RTK-GPS system results in degraded accuracy when exposed to highly dynamical behaviour.

This work present two alternative software and hardware position systems suitable for use in navigation system which apply RTK-GPS, namely Real-Time Kinematic Library (RTKLIB) with a Ublox Lea M8T receiver and a Piksi system. Both the Piksi and the Ublox receiver are single-frequency GNSS receivers. These systems will in this work be compared and their individual capability to provide accurate position estimate will be evaluated.

The RTK-GPS system is implemented in DUNE (DUNE:Unified Navigation Environment) framework running on an embedded payload computer on-board an Unmanned Aerial Vehicle (UAV).

The performance of these position systems are in this work investigated by experimental testing. The testing showed that the RTKLIB performed better than the Piski alternative, and further showed the tested navigation system provide sufficient quality for integration into a control and guidance system, allowing for automatic landing of an UAV in a net.

Contents

Chapter 1

Introduction

1.1 Background and motivation

Recent development of flying UAVs has been recognized to provide an attractive alternative to work previously performed by manned operations. Typical work which has attracted attention includes inspection, aerial photography, environmental surveillance and search and rescue. Today UAVs are mostly operated over land, however in the future this will include over sea as well. This will give some challenges which must be overcome. One of these challenges is that the UAV need to be able to perform a automatic landing.

An UAV can provide an attractive alternative for many maritime operation where today manned aircraft or satellites is the only solution. In the maritime sector UAV can be used in iceberg management, monitoring of oil spills, search and rescue and maritime traffic monitoring.

An important premise for successful and safe UAV operation, in particular at sea, is the provision of a robust system for safe landing of the UAV on a vessel following completed operations. A autonomous landing system require a robust guidance and navigation system, as well as the ability to generate a the landing path during flight operation. A requirement for the system is that the operator is able to monitor the state of the uav, including the navigation system e.g gps system. The the gps system looses its fixed solution during a critical phase a abort with an evasive manoeuvre might be required. The decision of wheater the uav should perform a evasive manoeuvre will be further explored in section (REF:EVASIVE).

Due to regulatory mandate there are restriction on the size of operational area for a uav. Different types of operation is LOS,EVLOS,BVLOS. During LOS the uav must be in line of sight of the operator, which restrict the area were a autonomous landing can take place. In addition there is the risk of loosing satellites during high dynamic behaviour which limits the type of landing path that are available. Therefore a flyable path must be generated for a arbitrary pose, which will provide a gentle landing for the uav. Present UAV

UAV in a maritime environment

A robust navigation system, which include two position estimation system for relative position determination of the UAV.

The scope of this thesis is the design, implementation and testing of an autonomous landing system for a uav. The main focus in this thesis will be on the navigation and path planning of the landing system. A fellow master student had the main focus of developing the control and guidance system, which will be explain in section ref.

This thesis contain a concept of a robust navigation system for autonomous landing of a UAV, and the implementation of the autonomous landing system. The landing system has been implemented together with a other student, and is a continuation of the master thesis from [**?**]. The navigation system that has been implemented apply rtk-gps for position estimation, and the robust navigation system apply range measurement from local transmitters together with the rtk-gps for position estimation. The range measurement hardware was not ready by the time this master thesis was written, however this thesis will explore different methods that can be applied in order to achieve a robust navigation system.

1.2 Related work

A disadvantage with a net recovery system that is stationary on the deck of a ship is the space requirement for the net, including the safty zone for the personnel required for the uav operation. The paper (Ref multicopter paper when published) addresses this problem by moving the net away from the ship by the means of multirotor uavs. The proposed net recovery system has the advantage that motion induced by the sea is removed, however there is the risk of losing the uav when colliding with the net. A solution that is currently explored is the use of hooks on the uav, which will allow it to grip the net.

Chapter 2

System

2.1 Navigation system

The navigation system apply RTKGPS for position and velocity measurement. The output from the RTKGPS software contains only the relative position from the base station, and not the position of the base station. Therefore a task was created to send send the global base station location to the navigation system, which enable the rest of the system to calculate the global position of the uav.

The base station position is received in the RTKGPS task in DUNE, were it's included in the GpsFixRtk message.

A task in the nest receive the gps position of the base, and the operator can monitor it in neptus. When the operator choose to fix the base station gps position a parameter update is send to the task, which will start to send a gpsfixrtk message to the uav.

TODO: Create figure that shows the information flow that is used to create the rtkfix message.

2.1.1 Operator interface

The operator use the Neptus platform as operational interface during the landing. The console includes information about the position of the uav, as well as the source of the position measurement. The operator can monitor the status of the gps system, including what is accepted by the navigation system. During a autonmous landing the operator must be fully aware of the status of the navigation system, such that an abort due to lost gps fix. This system can be expanded to include other sensors, like a ranging system, IMU, camera ex.

2.1.2 Position correction

The highly dynaimcal nature of the uav create a challenge for the navigation system due to the blocking of the gps antenna from the satellite constellation. The problem was reduced by using a gps receiver that has a high performance in satellite tracking, however this does not remove the problem. A float solution from the gps system is valid for some seconds after fix is lost, due to the predictive nature of the Extended Kalman filter in rtklib. However after a seartin amount of time the navigation system swithces over to use the position estimate from the pixhawk, which has a lower accuracy level then the rtk gps system. To increase the accuracy level a offset solution is proposed. By calculating the difference between the fixed rtk gps solution and the position solution from the pixhawk a offset can be found. If the offset can be assumed constant or quasi stationary it can be used to increase to accuracy level for the navigation system enough to allow for completion of critical phases of a manoeuvre. However tests showed that the offset was not constant nor quasi stationary. By applying the offset to the pixhawk position solution the accuracy level will increase, but not enough to allow for execution of critical manoeuvres. In order to make the navigation system more robust, some methods was explored.

2.2 Path generation

The area where the uav can operate is limited by the operator, which restrict the design of a landing path. In addition to the spacial limitation, the operator may choose the rate of descent which the uav should have during landing. The landing path system that has been design allows the operator to specify the length of the landing approach, including the angle of descent. The landing path follows the Dubins path (ref til teori) in the lateral plane, and straight lines in the longitudinal plane. The path is generated from an apitary start positing, and will create a contiues path toward the landing approach where the hight is given by:

$$h1 = \tag{2.1}$$

LIST opp ligningene for WP

The landing path is design with the assumption that the aerial space in which the uav operates is limited. The limitation can be the range of the uav, regulatory limits or weather. In addition the autonomous landing system must be able to perform a safe landing from any initial position. Furthermore the size of the virtual run way should be constructed by the operator. The type of uav operation dictates the maximum size of the landing path. Different types of uav operation is LOS, ELOS, BLOS and BRLOS. Only the first is considered in this thesis, which means that the pilot must have the uav in view during the entire flight. The operator must also be able to control the angle which the uav is descending, which means that the height of the landing path is fixed. Therefore the uav must be at the correct altitude before it can start descending toward the landing net.

A landing algorithm that is proposed consist of glideslopes that forms a staircase, of which the uav can ascend or descend in order to reach the correct heigh to start the landing. The path itself consist of straight lines between waypoints, however the landing path is not generated for a specific controller.

TODO: INSERT ALGORITHM HERE

The controller apply a goto manoeuvre in DUNE, which make a path manager task responsible for following the path. The advantage with this approach is the use of a module that has been thoroughly tested, which limits the source of error is the guidance system. The disadvantage is the path is picewise continues, which will introduce sudden changes in desired state for the controller. A curved path will remove this behaviour, however this will required a controller which is created specially for this path. I addition the autonomous landing achieved in [**?**] was performed with a straight line path.

2.2.1 The net approach

The net approach path consist a straight line in the lateral plain, and straight lines in the longitudinal plane. The net approach is defined by four way points which is defined as follows:

$$\mathbf{WP1} = \begin{bmatrix} -a0 \\ 0 \\ h_{nc} + a1\tan(\gamma_a) \end{bmatrix} \tag{2.2a}$$

$$\mathbf{WP2} = \begin{bmatrix} a1 \\ 0 \\ h_{nc} - a1\tan(\gamma_a) \end{bmatrix} \tag{2.2b}$$

$$\mathbf{WP3} = \mathbf{WP2} + \begin{bmatrix} a2 \\ 0 \\ a2\tan(\gamma_d) \end{bmatrix} \tag{2.2c}$$

$$\mathbf{WP4} = \mathbf{WP3} + \begin{bmatrix} a3 \\ 0 \\ 0 \end{bmatrix} \tag{2.2d}$$

were the description of the parameters used is given in table 2.1.

Parameter	description
$a0$	The distance behind the net
$a1$	The distance in front of the net
$a2$	The length of the glide slope
$a3$	The length of the approach towards the glide slope
γ_a	The net attack angle
γ_d	The glide slope angle

Table 2.1: Net approach parameters

2.3 Evasion

To ensure the safety of the operator a evasion controller is used to abort the landing when a successful landing is deemed infeasible or improbable.

2.4 Guidance system

The guidance system consist of two part. Sliding mode controller, and a los controller

2.4.1 Sliding mode controller

For course control the system use a sliding mode controller that was proposed in the paper [**?**], which USGES stability property.

$$\dot{x} = V_a \cos(\psi) + W_x = V_g \cos(\psi) \tag{2.3a}$$

$$\dot{y} = V_a \sin(\psi) + W_y = V_g \sin(\psi) \tag{2.3b}$$

$$p\dot{h}i = \frac{g}{V_a} \tan(\varphi) \tag{2.3c}$$

$$\dot{\varphi} = -\frac{\varphi - \varphi_{cmd}}{T_\varphi} \tag{2.3d}$$

$$W = \sqrt{W_x^2 + W_y^2} \tag{2.3e}$$

$$\epsilon(\varphi) = \begin{cases} \cos(\varphi), & \text{if } |\cos(\varphi)| \geq \epsilon' \\ \epsilon', & \text{if } 0 \leq \cos(\varphi) < \epsilon' \\ -\epsilon', & \text{if} - \epsilon' < \cos(\varphi) < 0 \end{cases} \tag{2.4}$$

$$\chi = \tan^{-1}(\frac{\dot{y}}{\dot{x}}) \tag{2.5}$$

$$\dot{\chi} = \frac{g \sin(\varphi)(V_a + \cos(\psi)W_x + \sin(\psi)W_y}{\epsilon(\varphi)V_g^2} \tag{2.6}$$

$$\chi_d = \tan^{-1}(-\frac{t}{\Delta} \tag{2.7a}$$

$$\dot{\chi_d} = -\frac{\Delta}{\Delta^2 + y^2}\dot{y} \tag{2.7b}$$

$$\ddot{\chi} = \frac{\Delta}{(\Delta^2 + y^2)^2}(2y\dot{y}^2 - (\Delta^2 + y^2)\ddot{y}) \tag{2.7c}$$

$$\tilde{\chi} = \chi - \chi_d \tag{2.8}$$

$$s = \dot{\tilde{\chi}} + \lambda\tilde{\chi} \tag{2.9}$$

$$u = -\lambda\dot{\tilde{\chi}} - \rho\text{sgn}(s) - K_d s \tag{2.10}$$