AutoDrone - Use of Autonomously Operated Drone Technology in Forest Inventory

An Approach Realized on Wireless Sensor Networks

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Abstract— **This paper describes the engineering solution of a system control technology for drones with the goal of autonomous drone flight on or over machine trails, skid trails, forest roads and similar line-like path in forest stands. The overall non-functional requirement here is for non-satellite positioning of the drone in real time based on a radio sensor network. The available open space above the line structures under the canopy of trees is used as the flight envelope. The problems of inaccurate satellite-based positioning inside the forestry environment are compensated primarily by the use of Wireless Sensor Networks for positioning. The goal is a valid recording of tree parameters and the creation of a digital map within the tree population. The control system of the drone is based on fused data from Wireless Sensor Networks, intertial sensors, satellite-based systems and visual position estimation. Our drone is thus able to automatically fly over freely selectable areas within the path without satellite-based positioning and thus fulfills the prerequisite for recording the tree parameters using suitable sensors. The practical application of this approach in the forest is presented and discussed.**

Keywords-Forest Inventory Monitoring; Wireless Sensor Network; Ultrawideband; GNSS Independent Localization; Drone

I. INTRODUCTION

For sustainable forest management, a solid data basis on the current stocking is absolutely necessary. In today's standard sampling method, trees in defined sampling circles are measured by terrestrial walking on the basis of a homogeneous, usually permanently established sampling grid. These data are stratified according to statistical procedures, aggregated and further processed for the calculation of forestry-relevant indicators. The current work process is becoming increasingly difficult for the following reasons:

- In the course of ecological forest conversion, mixed forests are aimed at that are rich in structure. This is associated with a highly developed vegetation layer near the ground, which makes accessibility and visibility extremely difficult for terrestrial methods.
- The sampling method used today is based on a personnel-intensive, time-consuming work process with a high cost burden for the forest enterprises. Although it is possible to reduce the costs associated with the surveys by means of the grids of the survey network, this is at the expense of the validity or statistical reliability of the results.
- With regard to accuracy, it must also be taken into account that manual measurement methods have a, high measurement error. Here, the error rate and measurement inaccuracies can be significantly reduced with the help of modern recording technologies.
- The process chains in forest management are for the most part still very extensive and decoupled. Automated data acquisition and subsequent automated data preparation allow the personnel and technical focus to be placed on data analysis and evaluations in the subsequent processing steps. Thus, the expertise is directed to the central tasks of silvicultural and forestry planning for the forest enterprise.

Against this background, the approach realized the use of an autonomously moving drone technology in forest inventory and operational planning is to be the basis for a later practicable, technologically mature procedure for the automated recording of individual tree parameters and the generation of population parameters relevant to planning and management. The focus of the work is on the technological innovation and implementation, the development of a control technology for drones with the goal of autonomous drone flight on or above machine trails, skid trails, forest roads and similar line structures within forest stands. Thereby, the available free space profile above the line structures is used as flight space. An appropriate flight altitude neglects the edges of the paths near the ground, which are covered by structures and which prevent a valid recording of the tree parameters inside the stand due to the obstructed view in terrestrial methods. The control system of the drone is based on fused data from radio sensor networks, inertial sensors, satellite-based systems and visual position estimation. A Light Detection and Ranging (LiDAR) sensor performs object avoidance. Our Drone is thus able to automatically fly over freely selectable areas within the path without global satellite-based (GNSS) positioning and thus fulfills the prerequisite for recording the tree parameters using suitable sensors. The specific tasks for this implementation were:

- Compensation of weak or non-existent GNSS signals in a forest environment through the use of range-capable Wireless Sensor Networks (WSN).
- Automatic flight stabilization with respect to altitude and required lateral positioning over the forest floor
- Multisensor data fusion and position filtering algorithms for autonomous flight primarily based on a WSN and secondarily based on an imaging (visioning) position module
- Application of a Wireless Sensor System for communication, localization and environment detection of drones
- Adaptation / further development of visioning position modules for the forest environment with regard to obstacle detection of trees, branches, bushes and segmentation of the forest floor as well as a constant flight altitude
- Implementation of a Simultaneous Localization And Mapping (SLAM) algorithm for autonomous flight within a geofender of the back alley

Figure 1 shows the system approach in this respect.

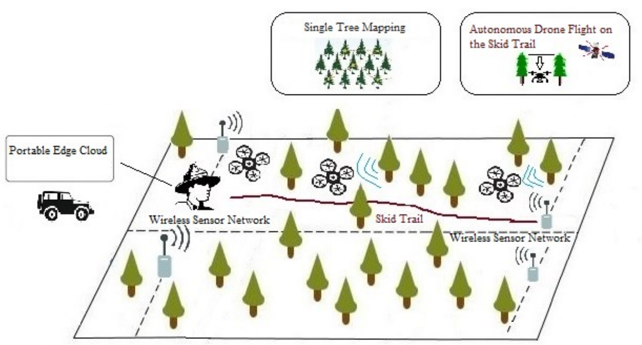

Figure 1. System approach for the use of drones in a forest environment.

The paper is structured as follows. After this introduction to the topic, which describes the problems and the boundary conditions for the use of autonomous drones in a forest environment, the state of the art in science and technology regarding drones and position technologies described in Section II. Section III gives an overview about the technological process flow for realizing a GNSS independent drone flight on the back alley in the forest. The test of the whole system setup and first flights on a test field are shown in Section IV. Section V addresses the evaluation of recorded measurement results of the performed test flights in a forest environment. In this regard, the results and resulting problems are discussed. The paper ends with a summary and an outlook on further work to solve the problems presented before.

II. State of the Art

Smaller drones or multicopters are relevant for the intended use in the forest on skid trails under the leaf canopy at a height of about 2 to 3 meters. This is due to the intended area of application of the drones, which are to fly autonomously under the treetops up to three meters above the forest floor, specifically in the area of skid trails. This eliminates large and heavy devices from the selection. Nowadays, drones can be used for very many disciplines in science and research due to their small design, improved control technology and falling prices. They open up entirely new perspectives for ecological research and environmental protection. For example, drones are already being used to map landscapes that are difficult to access or to take stock of endangered animal species. Today, drones already offer an efficient way to collect, aggregate and store or transmit data for scientific purposes using appropriately equipped sensor technology.

A. Overview of relevant Drone Technologies

A special focus is navigation in visual flight or with difficult or no GNSS reception. In principle, GNSS-based systems (mostly GPS and GLONASS) can currently achieve resolutions of barely more than three meters [1], which is sufficient for uninhabited landscapes - but not for urban areas or use inside buildings or in the forest on skid trails. In this regard, heavily attenuated or scattered GNSS signals under the treetops make autonomous drone flight enormously difficult to the point of impossible feasibility. Furthermore, they have to permanently avoid smaller and larger tree trunks, branches, smaller trees from the tree regeneration and shrubs. This requires a complex camera system, gyroscopes, accelerometers and ultrasonic sensors. This is the only way the aircraft can find out where it is and if there are any obstacles in its way. The state of the art is far advanced in this respect. Using so-called intelligent flight modes, the visual, inertial, ultrasonic and GNSS data are combined in a multi-sensor data fusion. This enables an assisted flight depending on the environment.

B. Introduction of Wireless Sensor Networks for Drone Positioning and Navigation in a Forestry Environment

In order to ensure autonomous flight in the forest environment, a WSN is adapted for positioning and applied to drones. Technical basis for this was the recent increased miniaturization as well as the advancing development of microsystem technology for the design of highly complex sensor nodes, which are combined as individual systems in an infrastructure-free and self-configuring WSN. In contrast to wired configurations, particular importance is attached to the radio-based transmission of information within the WSN and to a central coordination unit. The main task of these networks is the monitoring of extensive and usually difficult to access areas or extensive process chains, which can only be monitored by conventional systems with disproportionately high and uneconomical effort. The totality of all sensor nodes thus forms an information source with significant spatial extent, high flexibility and an almost unrestricted scaling behavior. Sensor nodes are generally highly complex individual systems consisting of a microcontroller, sensors or actuators, a memory, the communication unit and a power source. Thus, sensor nodes are basically capable of describing relationships with the environment, such as topological and geometrical information. The measured distance of sensor nodes to each other is, besides angular or simple presence information, the most commonly used form of neighborhood information and forms the data basis required for positioning and environment recognition methods. Broadband radio systems are used, which provide the required distance relations in the form of distance and angle measurements in corresponding real-time performance on the basis of the licensed Ultra-Wideband Spectrum (UWB). Within a WSN with a minimum of four fixed anchor nodes, a suitably equipped drone can fly autonomously along path on a forestry skid trail. The anchor nodes are static fixed in pairs on the trees. In principle, the anchor nodes can be attached to forestry vehicles, trees and other "static" points. The mobile nodes can be integrated, for example, in the clothing of forest workers or directly on mobile devices such as drones, chainsaws. Operationally and algorithmically, static and mobile nodes can switch properties [2].

III. OVERVIEW OF THE TECHNOLOGICAL PROCESS FLOW OF THE RADIO SENSOR NETWORK BASED DRONE FLIGHT IN THE FOREST ENVIRONMENT

First of all, the realized process flow is described. At least four anchor nodes are placed in the forest along the skid alley for Wireless Sensor Network-based tracking by a forestry employee. The anchor nodes are attached to trees at a height of 1 to 2 m with the antenna pointing towards the skid alley (see Figure 2)

Figure 2. Pinned anchor node on a tree [3].

This focuses the radio channel on the area of interest for the positioning within the skid alley (see red marked area in Figure 3).

Figure 3. Skidding trail for wood harvesting (a), area of interest for autonomous drone flight marked in red (b).

A. Technologies Used on the Drone

The corresponding wireless sensor for positioning determination is additionally attached and integrated as a so-called node on the drone control unit. In this regard, the connection was realized via different interfaces like Universal Asynchronous Receiver / Transmitter (UART) and Controller Area Network (CAN). By calibrating the initial anchor into a geodetic reference system, especially a World Geodetic System 1984 (WGS84) coordinate and determining the angular offset to the north, the coordinate transformation into global coordinates then takes place. The novelty now is that the drone's determined relative position within the WSN is converted to a global coordinate and provided to the drone controller as a fake National Marine Electronics Association standardized position data exchange (NMEA) message. Missing NMEA parameters are simulated or replaced. The drone does not recognize any difference between converted or simulated and real GNSS environment. In this context, the interconnection of the system components required for this purpose is shown in the following Figure 4.

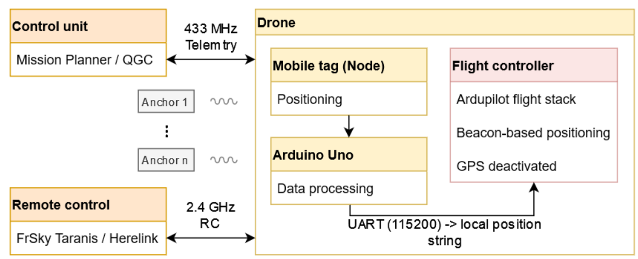

Figure 4. Interconnection between system components regarding the WSN and the drone, especially the flight controller and the integrated mobile node.

In the left part of the figure, the possibilities for drone control are shown. The control unit with the Mission Planner is a software for planning flight missions. It is used to plan the flight trajectory on the skid trail in prior, which the drone will then fly autonomously with the help of the WSN. Physically, the control unit is part of the so-called Ground Station (GS) and is equipped with a 433 MHz transceiver and connected to a computer running the planning software (see Figure 5). The trajectory planned on the computer is finally transferred via the telemetry channel to the drone and saved as a flight mission. Until now, the GS software used has been Mission Planner (MP) and QGroundControl (QGC).

Figure 5. Ground Station system architecture.

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The other remote control shown in Figure 4 serves as a fallback level to switch from autonomous flight to manual control. This is a commercially available programmable remote control (FrSky Taranis / Herelink Transceiver), which is connected to the drone with 2.4 GHz for pure flight control. This is only used in an emergency if problems are detected in autonomous flight.

The heart of the drone is the flight controller. This is where all sensor data ultimately converge. From this, the flight parameters are calculated and the corresponding rotors are controlled, for example, to execute the uploaded mission plan. The flight controller in this case is based on ArduPilot, an open source software for unmanned vehicles and the de facto standard for autonomous control of multicopters, fixed wing/Vertical Take Off and Landing (VTOL) gliders, helicopters, submarines and land vehicles. The FW variant for multicopters is called ArduCopter and is customizable. The configuration of the Firmware to the respective properties of the copter as well as its sensors is done via parameters. If changes to the FW are necessary, or if new modules not previously available, but have to be added such as positioning by using an extended Kalman filter (version 2 or 3), this can be implemented using the corresponding environment dependencies. To clarify this, the system architecture of the FW shown in Figure 6 is used with examples of the connection of further components. Via a companion computer (e.g., Arduino or Raspberry Pi on the drone) with the ground station, data of the copter can be retrieved, configured or changed. MAVLink (Micro Air Vehicle Link) is the protocol for communication between the components. The actual ArduPilot firmware is described in the Flight Code part. In this regard the flight controller, is a Cube Orange. It works according to the open Pixhawk standard, which defines guidelines for the implementation of the hardware (e.g., interfaces, voltage levels, etc.). The superordinate operating system is the RTOS (Real Time Operating System) ChibiOS. In normal operation, access to a large part of these components is not possible or not necessary, since the entire configuration of the system is done via the parameters [4].

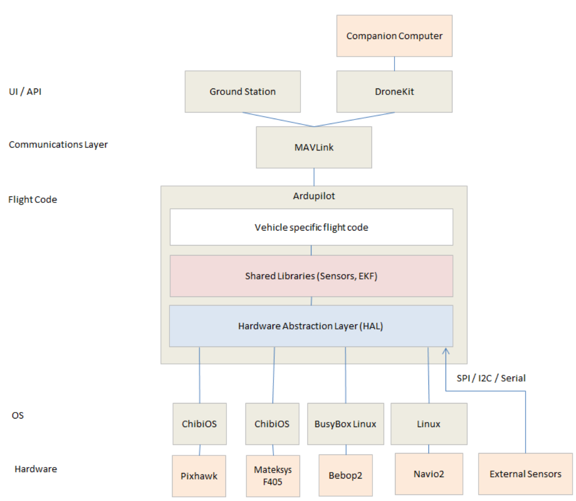

Figure 6. ArduPilot system architecture [4].

Finally, this section will look at the drone as itself. The drone is an PM Q685 Quadcopter and has the following technologies relevant to this particular system approach:

- Real Time Kinematic GNSS Positioning Modul
- Cube Orange Flight Controller
- HereLink Transceiver
- ArduPilot flight stack
- Ultrawideband sensor node (Pozyx) with Arduino Uno

The following Figure 7 illustrates the connection of the UWB sensor to the flight control of the drone. The Arduino Uno is responsible for the calculation of the positions to the individual anchors (PA1...PA4) as well as for the coordinate transformation.

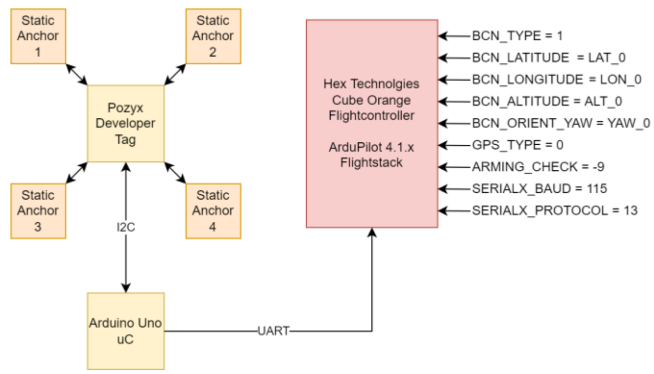

Figure 7. Integration of the UWB-based sensor node into the flight controller [4].

Finally, Figure 8 shows the operational drone modified for the goal of autonomous flight over a skid trail under the leaf canopy of trees in a forest environment. This fulfills the requirements for GNSS independent and sufficiently precise positioning with the use of a WSN distributed within the forest.

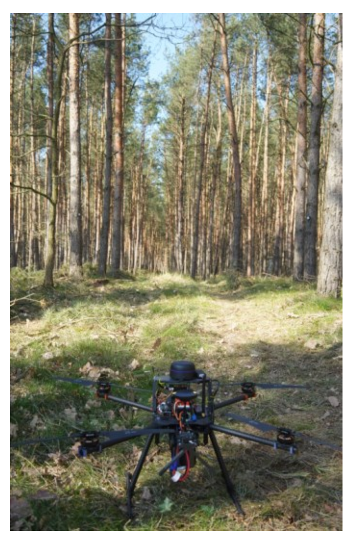

Figure 8. Operational ready drone at the launch point in the forestry environment at the skid trail.

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B. *Flight Mission Procedure*

The preparation of the flight mission, i.e., the trajectory to be flying on the skid trails follows the sequence diagram below (Figure 9). As a result, the flight trajectory is transferred to the drone as a flight mission. At this point, in principle the drone is ready itself for fly.

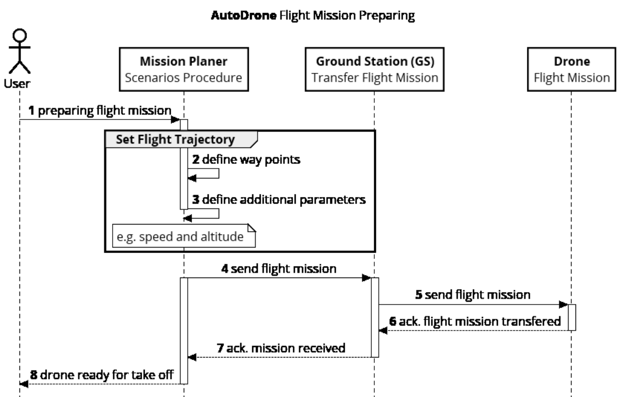

Figure 9. Sequence diagram for flight mission preparing.

In order for the drone to fly the trajectory autonomously in the forest environment, the following preparations must be fulfilled on site (see sequence diagram Figure 10).

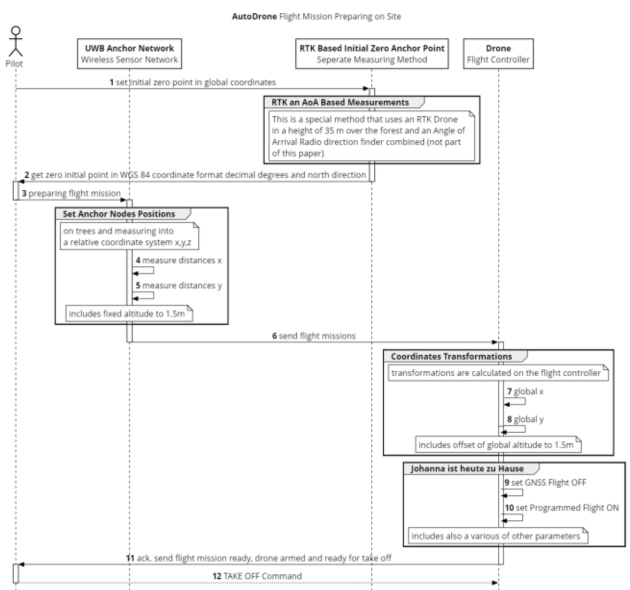

Figure 10. Sequence diagram for flight mission on site.

After this sequence diagram is completed, GNSS is deactivated and the drone flies the programmed route from the start and back again. During the flight all sensor data arriving at the flight controller are logged.

IV. TEST OF THE WHOLE SYSTEM SETUP AND FIRST FLIGHTS ON A TEST FIELD

The first flight tests and measurements were carried out on a test field. Here, the pilot still retained control of the drone. All process sequences were optimized and an artificial return path created on the test field was successfully flown autonomously in the end. For this purpose, a best-case scenario was designed and implemented. This included no sources of interference from the real environment such as trees, i.e., no or hardly any signal attenuation and multipath. The following figure 11 shows the test field and the flight area equipped with a WSN (marked in red).

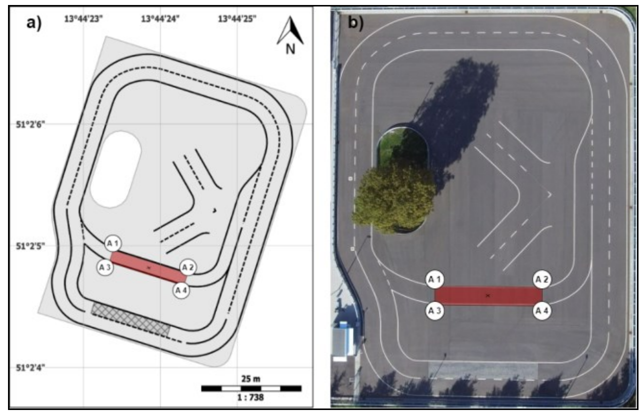

Figure 11. Overview about the test field as a surveyed map (a) and a satellite based view (b). The WSN area for flights is marked in red in each case.

The first interesting measurements are related to the distances between the anchors and the mobile node on the drone (see Figure 12). The symmetrical overlap of the distance measurements of all anchors at two points (outbound and return flight to the starting point) can be seen. There are minimal deviations in the 10 cm range of the distances during the entire flight. In summary, the distances are not very noisy and without detected outliers for this case. A comparison with the flight behavior confirmed this measurement.

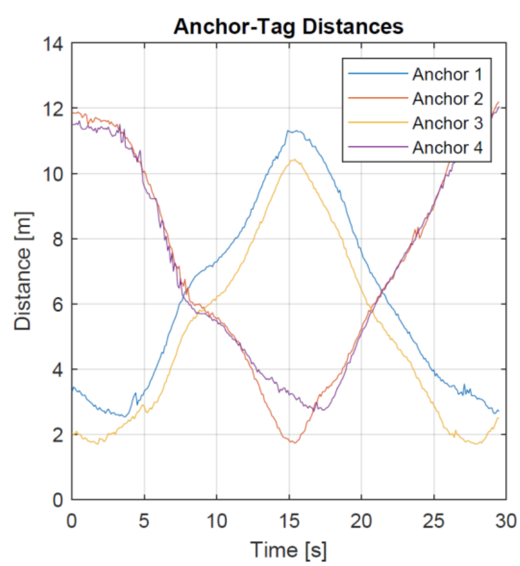

Figure 12. Anchor-Tag distance measurements during a flight in a radio sense optimal environment on a testfield.

Another important aspect of the investigation relates to the in-flight altitude measurement in the radio sensor network (see Figure 13). An optimization in terms of height measurement is the use of an ultrasonic sensor instead of the WSN. This type of sensor currently works more accurately due to the technical structure.

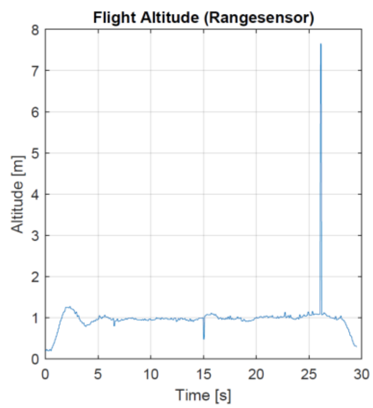

Figure 13. Flight altitude measurements during an autonomous flight on the test field.

The maximum height measurement ends at 7 meters, which is more than sufficient for our application. In the diagram you can see some outliers, which should not have been there due to a flight observation. A sudden drift of the drone in altitude could not be observed with the deviating altitude measurements (deviations at 15 s and 26 s). Since these deviations were short-lived, the Extended Kalman filter used compensated for them.

V. EVALUATION OF RECORDED MEASUREMENT RESULTS OF THE PERFORMED TEST FLIGHTS IN A FOREST ENVIRONMENT

The extensive test flights carried out in the forest confirmed the measurements on the test field. As results its presented here two interesting figures. Figure 14 shows the positioning of the drone with the mobile node/tag during the flight along the back road in the forest based only on the distance measurements of the WSN.

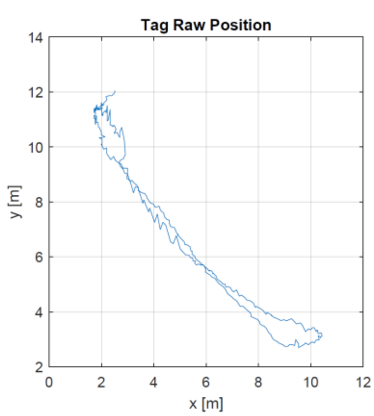

Figure 14. Positioning of the drone based on raw distance measurements.

It can be clearly seen that the positioning based on the raw data measurement of the distances varies with a deviation in the decimeter range. Thus, theoretically, no continuous smooth flight trajectory is possible on the sole basis of positioning in a WSN. Only by using the other onboard drone sensors, a smooth continuous flight trajectory becomes possible through a multi-sensor data fusion in the used Extended Kalman Filter (see Figure 15).

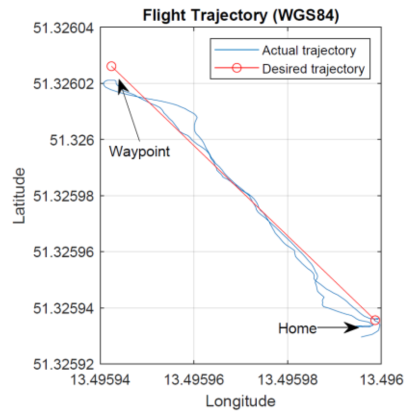

Figure 15. Data fused global positioning of the drone in the forestry environment.

VI. CONCLUSION AND FURTHER WORK

In this paper we have shown, that a GNSS-based positioning of a drone can be substituted by a local WSN for positioning. In this context, an already implemented solution of an autonomous drone flight within a skid trail was presented and discussed regarding its results (e.g., position accuracy, measurement setup). Further work relates to the objectives described in the introduction with respect to individual tree-to-tree mapping and radar-based tree condition detection.

ACKNOWLEDGMENT

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