CCA - COMPETENCE CENTRE
HTL Anichstraße

Diploma Thesis / Diplomarbeit

3D Drone Tracking

Image-Driven 3D Drone Tracking employing Multiple Stations for Agricultural Use

Submitted by

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Kurzfassung /Abstract

Eine Kurzfassung ist in deutscher sowie ein Abstract in englischer Sprache mit je maximal einer A4-Seite zu erstellen. Die Beschreibung sollte wesentliche Aspekte des Projektes in technischer Hinsicht beschreiben. Die Zielgruppe der Kurzbeschreibung sind auch Nicht-Techniker! Viele Leser lesen oft nur diese Seite.

Beispiel für ein Abstract (DE und EN)

Die vorliegende Diplomarbeit beschäftigt sich mit verschiedenen Fragen des Lernens Erwachsener – mit dem Ziel, Lernkulturen zu beschreiben, die die Umsetzung des Konzeptes des Lebensbegleitenden Lernens (LBL) unterstützen. Die Lernfähigkeit Erwachsener und die unterschiedlichen Motive, die Erwachsene zum Lernen veranlassen, bilden den Ausgangspunkt dieser Arbeit. Die anschließende Auseinandersetzung mit Selbstgesteuertem Lernen, sowie den daraus resultierenden neuen Rollenzuschreibungen und Aufgaben, die sich bei dieser Form des Lernens für Lernende, Lehrende und Institutionen der Erwachsenenbildung ergeben, soll eine erste Möglichkeit aufzeigen, die zur Umsetzung dieses Konzeptes des LBL beiträgt. Darüber hinaus wird im Zusammenhang mit selbstgesteuerten Lernprozessen Erwachsener die Rolle der Informations- und Kommunikationstechnologien im Rahmen des LBL näher erläutert, denn die Eröffnung neuer Wege zur orts- und zeitunabhängiger Kommunikation und Kooperation der Lernenden untereinander sowie zwischen Lernenden und Lernberatern gewinnt immer mehr an Bedeutung. Abschließend wird das Thema der Sichtbarmachung, Bewertung und Anerkennung des informellen und nicht-formalen Lernens aufgegriffen und deren Beitrag zum LBL erörtert. Diese Arbeit soll einerseits einen Beitrag zur besseren Verbreitung der verschiedenen Lernkulturen leisten und andererseits einen Reflexionsprozess bei Erwachsenen, die sich lebensbegleitend weiterbilden, in Gang setzen und sie somit dabei unterstützen, eine für sie geeignete Lernkultur zu finden.

This thesis deals with the various questions concerning learning for adults – with the aim to describe learning cultures which support the concept of live-long learning (LLL). The learning ability of adults and the various motives which lead to adults learning are the starting point of this thesis. The following analysis on self-directed learning as well as the resulting new attribution of roles and tasks which arise for learners, trainers and institutions in adult education, shall demonstrate first possibilities to contribute to the implementation of the concept of LLL. In addition, the role of information and communication technologies in the framework of LLL will be closer described in context of self-directed learning processes of adults as the opening of new forms of communication and co-operation independent of location and time between learners as well as between learners and tutors gains more importance. Finally the topic of visualisation, validation and recognition of informal and non-formal learning and their contribution to LLL is discussed.

Gliederung des Abstract in **Thema**, **Ausgangspunk**, **Kurzbeschreibung**, **Zielsetzung**.

Projektergebnis Allgemeine Beschreibung, was vom Projektziel umgesetzt wurde, in einigen kurzen Sätzen. Optional Hinweise auf Erweiterungen. Gut machen sich in diesem Kapitel auch Bilder vom Gerät (HW) bzw. Screenshots (SW). Liste aller im Pflichtenheft aufgeführten Anforderungen, die nur teilweise oder gar nicht umgesetzt wurden (mit Begründungen).

Erklärung der Eigenständigkeit der Arbeit

EIDESSTATTLICHE ERKLÄRUNG

Ich erkläre an Eides statt, dass ich die vorliegende Arbeit selbständig und ohne fremde Hilfe verfasst, andere als die angegebenen Quellen und Hilfsmittel nicht benutzt und die den benutzten Quellen wörtlich und inhaltlich entnommenen Stellen als solche erkenntlich gemacht habe. Meine Arbeit darf öffentlich zugänglich gemacht werden, wenn kein Sperrvermerk vorliegt.

Ort, Datum Verfasser 1

Ort, Datum Verfasser 1

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1 Introduction

Current drone tracking systems often rely on onboard equipment, requiring expensive hardware installations on each drone. This thesis focuses on developing a ground-based 3D tracking system capable of monitoring "dumb" drones—those without onboard tracking systems—using calibrated and synchronized ground stations equipped with image processing technology.

The goal of this project is to design and implement a functional prototype consisting of three ground stations that can accurately track drones in three-dimensional space. The system aims to calculate drone positions by processing images captured by the ground stations and display the tracked drones through a 3D visualization interface.

This topic is important because it addresses the high costs and limitations associated with current drone tracking methods. By eliminating the need for onboard tracking hardware, the proposed system could make drone tracking more accessible and cost-effective. The problem of tracking drones without onboard systems is significant, as it could expand the usability of drones in various industries where cost and simplicity are critical factors.

Solving this problem is crucial for reducing operational costs and enhancing the scalability of drone applications. Existing research primarily focuses on onboard tracking solutions or GPS-based methods, which may not be feasible for all situations due to cost or technical constraints. This thesis aims to contribute to the field by providing an alternative ground-based tracking solution, potentially filling a gap in current drone tracking technologies.

This topic was chosen because it combines practical engineering challenges with significant potential benefits in the field of drone technology. By developing a ground-based tracking system, we aim to offer a viable alternative to existing methods, addressing a current need in the industry.

1.1 Detailed Task Description

Main goal: Track drones with multiple ground stations

1.1.1 Hardware

1.1.1.1 Computer

Responsible: Krahbichler Lukas

Select hardware capable of efficiently handling the required image processing and running the 3D-GUI.

1.1.1.2 Camera

Responsible: Krahbichler Lukas

Select, procure, and set up a suitable camera.

1.1.1.3 Display

Responsible: Krahbichler Lukas

Select and integrate a display for visualization, ensuring compatibility with other hardware components.

1.1.1.4 Power Supply

Responsible: Krahbichler Lukas

Design or select a power supply system that meets the requirements of all hardware components to ensure stable and efficient operation.

1.1.1.5 Data Transfer

Responsible: Krahbichler Lukas

Select and test a secure and fast communication medium for data transfer. - Indepedence, security

1.1.1.6 Calibration

Responsible: Krahbichler Lukas

Select and integrate calibration hardware essential for precise positioning and synchronization of the stations.

1.1.2 Housing

1.1.2.1 Primary Station Housing

Responsible: Prantl Niclas

Design, test, and build housing for the primary station, incorporating components such as a display and calibration hardware.

1.1.2.2 Secondary Station Housing

Responsible: Prantl Niclas

Design, test, and build housing for secondary stations.

1.1.3 Programming

1.1.3.1 3D Angle Calculations

Responsible: Prantl Niclas

Develop algorithms to calculate drone positions based on data from the stations.

1.1.3.2 Camera Tracking

Responsible: Krahbichler Lukas

Implement software to track drones within the camera's output stream.

1.1.3.3 Data Transfer

Responsible: Krahbichler Lukas

Develop and implement a system to synchronize data transfer from secondary stations to the main station.

1.1.3.4 Calibration

Responsible: Krahbichler Lukas

Create software to perform calibration procedures, accurately calculating relative positions and rotations of the stations.

1.1.3.5 3D Visualization

Responsible: Prantl Niclas

Program a 3D visualization interface to display tracked drones, integrating data from all stations.

2 State of the Art: Market Analysis

2.1 Industry Overview and Market Potential

Drones are transforming agriculture by offering innovative solutions to enhance efficiency and sustainability. As reported by Chaundler in The New York Times [4], companies like CO2 Revolution are using drones to plant seeds in inaccessible areas, showcasing the potential of drone technology in reforestation and agricultural applications.

The global agricultural sector faces significant challenges, including the need to increase food production to meet the demands of a growing population and to address climate change impacts [16]. Traditional farming methods are often insufficient, leading to a surge in the adoption of drones for various agricultural purposes.

2.1.1 Applications of Drones in Agriculture

Drones are used in agriculture for a wide range of applications:

- **Crop Monitoring and Mapping:** Drones can provide high-resolution aerial imagery, enabling farmers to monitor crop health, identify pest infestations, and assess soil conditions in real-time [16, 19].
- **Precision Spraying:** With precise positioning, drones can apply fertilizers, pesticides, and herbicides precisely where needed, reducing chemical usage and minimizing environmental impact [11, 5].
- **Irrigation Management:** Drones assist in detecting variations in soil moisture levels using thermal cameras, helping optimize irrigation systems and conserve water resources [16].
- **Planting and Seeding:** Some drones are designed to plant seeds over large areas efficiently, particularly useful in reforestation efforts and hard-to-reach terrains [4].

2.1.2 Market Growth and Potential

The agricultural drone market is experiencing significant growth. Valued at $0.88 billion in 2020, it is projected to reach $5.89 billion by 2030, with a compound annual growth rate (CAGR) of 22.4% [19]. Key factors contributing to this growth include:

- **Demand for Increased Food Production:** Global population growth drives the need for higher agricultural output, encouraging the adoption of efficient technologies like drones [16].
- **Technological Advancements:** Improvements in drone capabilities, such as enhanced sensors and longer flight times, make them more practical for agricultural applications [11].
- **Adoption of Precision Farming Techniques:** Farmers are increasingly using drones for site-specific crop management to optimize resource use and increase yields [19].

2.1.3 Challenges and Opportunities

While the potential is significant, the adoption of drones in agriculture faces several challenges:

- **Regulatory Barriers:** Strict government regulations on airspace and drone operations can hinder deployment [16].
- **High Initial Costs:** The expense of acquiring and maintaining advanced drones may be prohibitive for small-scale farmers.
- **Privacy and Safety Concerns:** The use of drones can raise privacy issues and pose safety risks to people and animals if not operated correctly [15].

Our solution addresses these challenges by offering cost-effective drone tracking systems that reduce initial costs by eliminating the need for expensive onboard navigation systems. By utilizing ground-based tracking, our drones can be simpler and more affordable, enhancing operational safety and accessibility for small-scale farmers. Moreover, we can leverage government support initiatives like Austria's "Smart Farming" action plan, which provides funding and resources to integrate digital technologies into agriculture [3]. Additionally, implementing privacy and safety features such as geofencing and privacy-by-design principles ensures compliance with regulations and builds trust among users [17].

2.2 Target Group Definition

Our ideal customers are small to medium-sized agricultural enterprises, individual farmers, and agricultural cooperatives with limited budgets. They seek cost-effective solutions to modernize their farming operations with drone technology without the high expenses associated with advanced onboard systems.

Key Characteristics

- **Demographics**: Farmers and managers aged 35–60 with practical experience in agriculture, often fitting the "Progressive Realists" or "Adaptive-Pragmatic Middle Class" Sinus-Milieus [18].

- **Geographics**: Located in rural agricultural regions such as Lower Austria, Styria, Upper Austria, and Tyrol.
- **Psychographics**: Value efficiency, sustainability, and are open to adopting new technologies that improve their farming practices.
- **Behavioral**: Make purchase decisions based on cost-benefit analysis, attend local agricultural events, rely on recommendations from peers and local networks.
- **Needs**: Affordable and reliable drone tracking systems that are easy to implement and help optimize farming operations.
- **Technographics**: Moderate technological proficiency, use basic agricultural management tools, interested in user-friendly technology solutions.

2.3 Buyer Personas

Persona 1 (Core): Thomas Bauer

- **Age**: 52
- **Role**: Owner of a medium-sized family farm
- **Location**: Lower Austria
- **Goals**: Increase crop yields and operational efficiency through affordable technology
- **Pain Points**: Limited budget for high-end drones; needs cost-effective tracking solutions that don't require extensive technical expertise
- **Behavior**: Reads local agricultural journals, attends regional farming expos, values practical and easy-to-use solutions

Persona 2 (Core): Maria Hofer

- **Age**: 40
- **Role**: Owner of a small organic farm
- **Location**: Graz, Styria
- **Goals**: Implement sustainable farming practices with the help of affordable technology
- **Pain Points**: Needs reliable tracking solutions that align with organic farming principles; constrained by a tight budget
- **Behavior**: Active in local farming communities, follows agricultural trends online, seeks eco-friendly and cost-effective solutions

Persona 3 (Peripheral): Andreas Schneider

- **Age**: 55
- **Role**: Manager of a farming cooperative
- **Location**: Upper Austria
- **Goals**: Enhance productivity for cooperative members through shared resources and technology
- **Pain Points**: Finding affordable technology solutions that can be easily adopted by multiple farmers with varying levels of technical skill

- **Behavior**: Engages with cooperative members, attends agricultural seminars, values solutions that offer collective benefits

2.4 Competitor Analysis

The agricultural drone market in Austria and globally is highly competitive, with key players offering advanced precision farming solutions. This analysis focuses on three major competitors relevant to the Austrian market:

1. **Dronetech by Immotech (Austria):** Dronetech partners with Huawei to develop 5G-enabled smart farming drones. They modify DJI drones, already equipped with Global navigation satellite system (GNSS), Real-Time Kinematic (RTK), and obstacle avoidance cameras, adding custom Three-Dimensional (3D)-printed parts to optimize them for agricultural needs [14, 8]. Enhancements include high-resolution cameras and sensors, leveraging Huawei's cloud computing and AI for real-time data analysis. This enables precise application of water, fertilizers, and pesticides, reducing waste and environmental impact. A key challenge they face is limited 5G network coverage [13, 12, 10].
2. **DJI - Da-Jiang Innovations Science and Technology Co. (China):** DJI, a global drone leader, offers expensive high-tech agricultural drones like Agras T50, T25, and Mavic 3M for tasks such as spraying, mapping, and crop monitoring. They use GNSS and RTK for precise positioning, radar and vision sensors for obstacle avoidance, and Radio, WiFi, and Bluetooth for communication. Accessories like DJI Relay enhance their range in complex environments [6, 7]. In Austria, partners like Drohnenring distribute DJI's products, offering consultation, sales, training, and support [9].
3. **AgEagle Aerial Systems Inc. (USA):** AgEagle specializes in agricultural mapping drones like eBee X. Equipped with GNSS and RTK, they achieve centimeter-level accuracy without ground control points. They communicate via radio links up to 3 km with secure encryption. LiDAR sensors provide obstacle avoidance and controlled landings. AgEagle offers software like eMotion and Measure Ground Control for flight planning and data processing [1, 2].

2.4.1 Competitive Landscape

The Austrian agricultural drone market includes local firms like Dronetech, partnering with global tech companies, and international players like DJI and AgEagle, offering advanced drone technology and services. Competition centers on integrating cutting-edge technologies like 5G, AI, GNSS/RTK positioning, and advanced imaging to enhance precision farming. Competitors offer sophisticated communication systems, precise positioning, and advanced software solutions to meet modern agriculture's needs.

2.4.2 Our Differentiation and Positioning

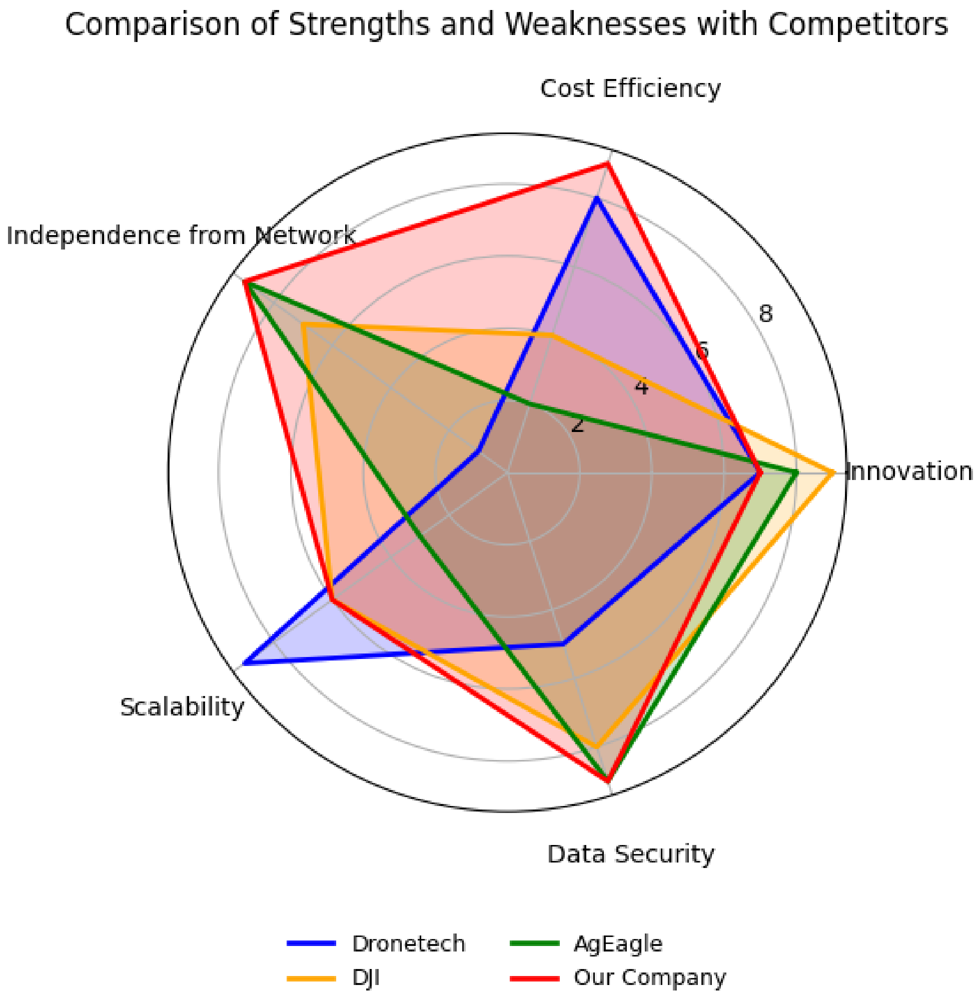

Figure 1: Comparison of Strengths and Weaknesses with Competitors

Source: Own illustration created with Matplotlib in Python

Our ground-based 3D drone tracking system offers an affordable and independent solution for Austria's agricultural sector. By using calibrated ground stations with advanced image processing, we eliminate the need for expensive onboard positioning and obstacle avoidance systems. This allows us to deploy simpler drones, reducing costs, maintenance complexities, and payload restrictions. As a result, small to medium enterprises can access modern drone technology, overcoming challenges like network coverage limitations and high equipment costs, making it a practical tool for improving farming operations without substantial investment.

Our approach provides several key benefits:

- **Enhanced Efficiency and Cost Savings:** Without heavy onboard sensors, drones are lighter and consume less energy, increasing flight times and coverage area. They can carry more payloads like seeds, fertilizers, or pesticides, enhancing operational efficiency. Reduced complexity lowers maintenance and failure risk, leading to cost savings and making precision agriculture accessible to farmers with limited budgets.

- **Secure, Independent Communication:** Our local communication system operates independently of network infrastructure, ensuring reliability in areas with connectivity issues. Unlike competitors relying on 5G, our system enhances reliability, data security, and privacy by processing tracking data locally.
- **Scalability and Flexibility:** Our ground stations can track multiple drones simultaneously without adding complexity or weight to drones. This enables scalable operations, allowing farmers to expand fleets without significant additional investment.

2.5 Conclusion

The market analysis reveals a significant opportunity for our ground-based 3D drone tracking system in the agricultural sector. As drone adoption in agriculture accelerates, our solution addresses key challenges like high costs, dependence on network infrastructure, and the complexity of onboard systems by eliminating the need for expensive onboard positioning, and obstacle avoidance equipment. By enabling the use of simpler, more affordable drones with increased payload capacity and simplified maintenance, we offer a unique value proposition that differentiates us from competitors relying on complex onboard technologies. Our system aligns with the needs of small to medium agricultural enterprises seeking efficient and sustainable technologies without the barriers of high initial investment and technical complexity. Further research and engagement with industry stakeholders will refine our understanding of target customers and support a successful market entry, positioning us as a competitive player in the agricultural drone market focused on accessibility and practicality.

3 Solution Idea

3.1 Hardware

3.1.1 Computer

Compare boards online (power for image processing needed)

3.1.2 Camera

Compatible (with single board computer), good value camera. 4k would be good (for higher distance tracking)

3.1.3 Display

Search for compatible Full HD 8-12 inch display for a reasonable price

3.1.4 Power Supply

USB-C input Battery-powered Power-Supply on PCB for all components

3.1.5 Data Transfer

- Local radio communication (could double for approximate direction determination for calibration)

3.1.6 Calibration

PCB to connect everything (with Arduino for the things our Image Processing Unit is not capable of doing) - PCB will also integrate Power-Supply

PCB: - Power Delivery - ToF Laser - Communication - Stepper - Servo - Gyro/-Mag/Acc 9DOF - End switch

With 40pin cable to Computer and/or with extra Chip

3.2 Housing

3.2.1 Primary Station Housing

re.

3.2.2 Secondary Station Housing

3.3 Programming

3.3.1 3D Angle Calculations

3.3.2 Camera Tracking

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3.3.4 Calibration

3.3.5 3D Visualization

4 Solution

4.1 Hardware

4.1.1 Computer

- NVIDIA Jetson Nano: too expensive and focuses on AI-Power
- ASUS Tinker Board S: not enough processing power?
- ArmSom Sige7: Good value, good processing performance

4.1.2 Camera

When choosing the ArmSom Sige7, we reviewed their other hardware to guarantee compatibility, rather than relying on third-party components. We found that they provide a 4K camera module that is fully compatible and reasonably priced.

4.1.3 Display

We found that ArmSom offers a 10.1-inch Full HD display that is fully compatible and reasonably priced.

4.1.4 Power Supply

4.1.5 Data Transfer

4.1.6 Calibration

For calibration the main station can rotate its head (camera, laser, communication) in 2 axes - Precise ToF Laser with enough range (30 meter at least) - Use Radio-Com hardware for approximate direction determination

Calibration/start-up procedure:

- Calibrate C-axis stepper (end-switches) - Calibrate B-axis servo (check max rotation with gyro) - Move motors to neutral position - Connect with other stations (all stations in neutral position) - Get 3d magnetic orientation of every station - Find estimate directions by sweeping and checking RSSI - Measuare exact distance and direction (2 axes) with ToF Laser - Move all cameras to perfect position for best maximum coverage in air (only if secondary stations can do that) - Calculate exact relative positions/angles of cameras.

4.2 Housing

4.2.1 Primary Station Housing

4.2.2 Secondary Station Housing

4.3 Programming

4.3.1 3D Angle Calculations

4.3.2 Camera Tracking

4.3.3 Data Transfer

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5 Conclusion

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