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Whitepaper

Applications of drones in warehouse operations

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Summary

Drones have shown high potentials in the logistics industry. It has been speculated that this market will grow by $29 billion by 2027 with an annual growth rate of almost 20% [1]. Drones have particularly found applications in warehousing operations [2]. Recent technological advances of drones such as visual based navigation and sensors [3] enable indoor applications of drones. In addition to the advancement of drone technology, a main reason is that the scale of warehouses is increasing due to the growth of global e-commerce. For instance, drones can be used for automated inventory checks [4] and intralogistics. Using drones for such applications can help warehouse managers to remove tedious and dangerous tasks.

This white paper reports 12 identified use cases of indoor drone applications in warehouses. We classify three different application areas: inventory management, indoor intra-logistics and inspection & surveillance. The analysis indicates that using drones for inventory management applications have the highest potential in warehouses. Indoor intra-logistics is not yet entirely feasible due to current technological limitations in power supply and payload. Drones can potentially also be used for inspection and surveillance, but there is not much public evidence on this application area yet.

Content

Indoor Drone Applications

Benefits: Indoor applications have less boundary conditions compared to outdoor applications. Main benefits of indoor applications are the following:

✓ **Less hazardous tasks**
- No ladder climbing and dangerous inspections anymore

✓ **Stable weather conditions**
- Constant weather conditions (no wind, snow rain or fog)

✓ **Less restrictive regulations**
- Much easier to get approval compared with outdoors

✓ **Attractive investment costs**
- Fast return on investment due to manageable acquisition costs of hardware (small drones)

Technological challenges: Problems such as violating airspace, collisions with birds and manned aircrafts, and flying in hazardous areas such as airports are not inhibitive factors for indoors. However, there are several technological challenges of indoor applications of drones:

✗ **Limited hovering area**
- Many obstacles which increase complexity

✗ **Integration**
- Time consuming integration of drones into existing processes

✗ **Navigation**
- GPS-denied environment

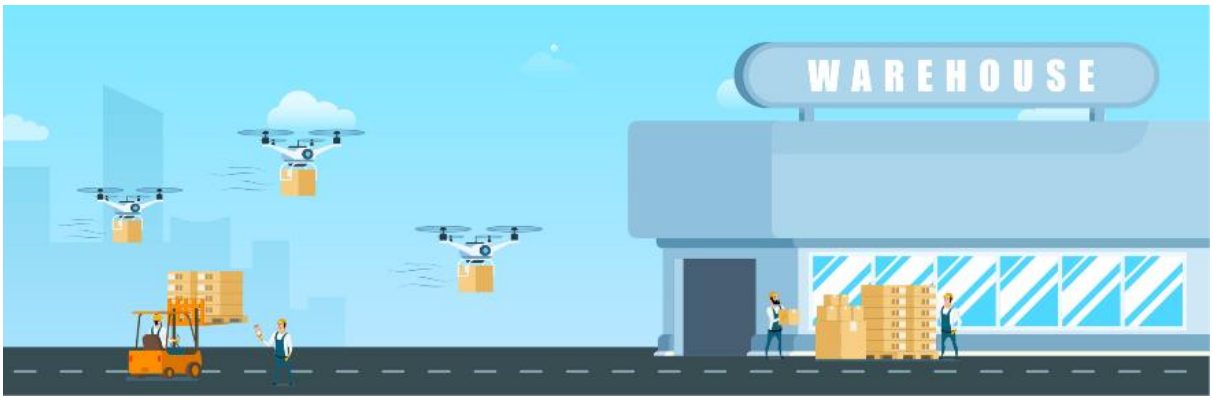
✗ **Safety**
- Potential drone failures & explosions (battery)

Ethical challenges: The ethical challenges are mostly concerned with privacy and data protection, but there is also concerns about noise and the feeling of safety risks.

✗ **Privacy issues**
- Data collection and preprocessing rules

✗ **Concerns of Unions**
- Some labor unions are increasing pressure on regulatory bodies

✗ **Insurance**
- Key-question: Who is guilty in case of crash?



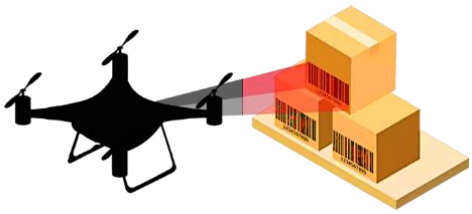
Drones in Warehouse Operations

The use of drones in warehouses has been increasing over the past years. Large warehouses are aiming to increase efficiency by investing more in automation and robotics. This is not without precedence since the cost of warehousing operations account for 30% of the total costs in logistics [5]. Furthermore, difficulty to attract skilled labors, increasing demand for customer services and the rise of e-commerce have intensified the need to further increase efficiency in warehouse operations.

The fourth industrial revolution is also affecting warehouses. They become more digital and more connected—as in "warehouse 4.0". New scanning technologies, bar codes, QR codes, radio frequency identification (RFID) technologies and artificial intelligence (AI) enable drone-driven automations in warehouses. Moreover, onboard computing power and efficient algorithms allow for the implementation of scalable drone applications [6]. However, the structure of warehouses are diverse with different complexities, which impose constraints for the rollout of a drone program. They differ in terms of geographic location, type of stored items, layout (e.g. shelf, pallets, and boxes), size and technology. The function of warehouses is also diverse. For example, a distribution warehouses is operating differently from cross-docking warehouse and factory warehouses for raw materials and finished goods.

Drones have started to play a central role in the automation of current warehouses. They are popular due to their ability of drones to fly and hover autonomously, avoid obstacles in different warehouse layouts, navigate indoor, land precisely and potentially operate in fleets.

The three most promising areas of indoor drone use cases in warehouses are inventory management, intra-logistics of items, as well as inspection and surveillance.



Inventory Management

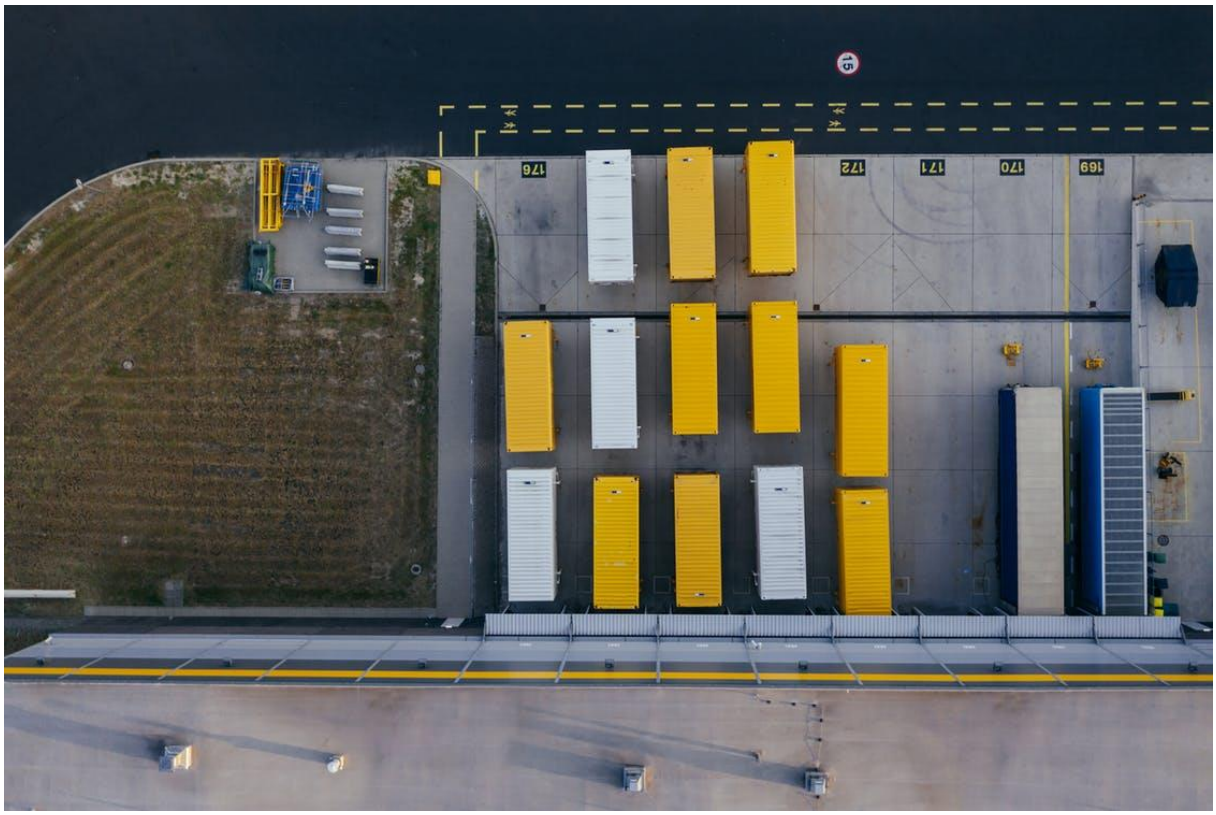
In the area of inventory management, drones can be used for the following tasks: inventory audit, inventory management, cycle counting, item search, buffer stock maintenance, and stock taking. Stock taking is the physical verification of the quantity of items stored in warehouses. Stock taking is often done annually or by the end of the fiscal year. Whereas cycle counting describes the process of counting a partial amount of a warehouse's inventory on a more frequent basis [7]. This task is usually performed daily or weekly by a small trained team of inventory control staffs. They walk or drive to a designated location in the warehouse, scan the barcode of the item, count the units and move on to the next location following their schedule. Even though this method increases the inventory accuracy compared to the annual one-time inventory checks, there are still several downsides. Among others, cycle counting is slow (manual task), labor-intensive (several inventory staffs are needed), dangerous (risky operations due to working in high altitudes), expensive (labor costs) and error-prone (highly repetitive tasks). Drones can add value to optimize this process [8]. The main objectives of using drones for inventory management are to increase the inventory accuracy, decrease labor costs, and minimize dangerous tasks for the workforce.

Intra-Logistics

Drones can also be used for intralogistics. For instance, they can transport parts from warehouses to workshops in factories. The ability of drones to follow pre-defined flight paths and carry items show good potential for indoors such as on-site express delivery of tools and spare parts as well as lubricants. However, significant limitations for intralogistics is payload, gripping/placing movements and navigation [9].

Inspection & Surveillance

Drones can be a viable alternative to replace manual inspection and surveillance operations in warehouses. Drones are already used for inspection in many industries such as construction, petrochemical, oil and gas, and power generation. Indoor use cases of drones for inspection is also growing. In warehouses, drones can for example inspect roofs, racks, pallet placements, walls, and ceilings. The growth of warehouse operations and customer demand makes inspection processes expensive and difficult. Indoor inspection tasks often require skilled inspectors and sometimes work is obstructed during inspections. Indoor drones are a perfect fit for tasks that require monitoring and inspection in dangerous areas or high altitudes [10]. Drones can also be used for regular surveillance routes to prohibit theft and other unwanted behavior.



Use Cases

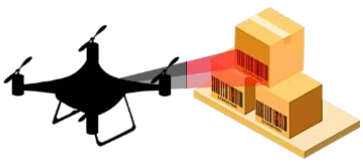
Area	Drone Partner	Industry Partner	Location, Year	Navigation	Status	Technological Readiness	Autonomous Level (0-5)
Inventory Management	PINC	Kenco Logistics	US, 2016	Vision	In-use	Commercial	4-5
	eyesee (Hardis Group)	FM Logistics (among others)	FR, 2016	Vision	In-use (9x)	Commercial	4-5
	Aeriu	IKEA Soroksár	H, 2018	Human	Experimental	Prototype	2
	DroneScan	LF Logistics	SA, 2018	Human	Experimental	Market launch soon	1
	DeltaDrone	GEODIS	FR, 2017	Vision with AGV	Experimental	Unique prototype	3
	InventAIRy	Rigterink Logistik	DE, 2017	Vision	In-use	Commercial	4-5
	Infinium Robotics	Bolloré Logistics	SG, 2017	Vision with AGV	In-use	Commercial	4-5
Intra-Logistic	Ascending Techn. (Intel)	Audi	DE, 2015	Human	Future	Prototype	1
	Not given	Fraunhofer Institute (IML)	DE, 2016	*Not given*	Future	Prototype	1
	Not given	Walmart	US, 2017	*Not given*	Future	Patent	N/A
Inspection & Surveillance	*Not given*	Ford	UK, 2018	Human	Experimental	Prototype	0
	Vtrus	*Not given*	US, 2018	Vision	Experimental	Market launch soon	5

Discussion

Highest Potential Use Case

Inventory management applications appear to have the highest potential for use in warehousing operations. Seven of the 12 use cases fall into this category and they are also the ones that (reportedly) have beyond testing phase in some companies. To date, using drones for intra-logistics seem to be difficult due to technological challenges, namely power supply and payload. There is limited evidence for successful inspection & surveillance applications in warehouses.

Several drone solution providers are gearing up to enter the drone inventory management market. For instance, Corvus Robotics claimed to launch their new autonomous warehouse inventory solution in the beginning of 2019 [11]. In addition, Linde Material Handling, the leading European company in warehouse optimization, stated at the LogiMAT trade fair in Stuttgart in 2017, that the market launch of their inventory checking solution "Flybox" is scheduled for 2018 at earliest [12]. Verity Studios is also testing prototypes in their lab while elaborating a strategy of how to potentially enter the drone inventory market [7, 13].

1st		- Inventory management is the most discussed warehouse use case -Many companies report to have implemented drones for this task
	2nd	- Warehouses are not in key-focus of surveillance drone manufacturer - Drone surveillance technology is mature & ready for implementation
- Main problem for intra-logistics: Trade-off between power supply and payload - Often used as a "marketing case"		3rd

State of Drone Technology

The most challenging part to reach full automation (level 5) is concerned with indoor navigation. Due to insufficient navigation accuracy, drones are not likely to fly autonomously in any of the application areas in the next few years. Yet, recent advances of promise that drones will achieve high precision for indoor navigation in the near future.

Vision based algorithms provide a promising way to achieve 100% accuracy. To date, one of the most advanced visual SLAM algorithm achieves an accuracy of 5cm. Yet, visual based SLAM outperforms other localization technologies such as Ultrawide-Band (UWB). The radio frequency based technology is often used for the tracking of floor conveyors such as forklifts or pallet trucks with relatively low accuracy of 10-30cm, which is not a suitable alternative for indoor localization of drones. Other emerging technologies can potentially increase the accuracy of visual based SLAM. For instance, light detection and ranging (LiDAR) technology has high potentials for indoor navigation. It is a method with high-precision and measures distance to a target by illuminating the target with pulsed laser light. Leica Geosystem co-developed a drone with DJI [14] using a combination of LiDAR sensors and cameras. The so called “Aibot” achieves an accuracy of 2.5cm over an area of 10ha (100’000 square meters). However, the weight of drone is almost 10 kilograms that impose constrains for indoor environments.

An example of an advanced available technology for high precise navigation for indoors is the technology of Vtrus [15]. This technology combines 3D depth sensors and 3D scanner with 360° wide-angle cameras to achieve the highest possible accuracy. Their vision based simultaneous localization and mapping algorithm (SLAM) is processing millions of camera pixels in parallel, as often as 30 times per second. In addition, they are able to reproduce a 3D map and locate the drone inside the map. The indoor navigation solutions from PINC [16], inventAIRy [17] and eyesee [18] are also vision based and are similar to the Vtrus’s technology. For example, PINCs solution is not only able to check inventory but also to localize it. InventAIRy states that their software is capable of vision-based inspection providing information on packaging quality, pallet quality and possible damages on goods. Mastering the challenge of indoor navigation is the key to success for indoor drone implementation in warehouses but also for other indoor environments.

To further increase the localization accuracy, Geodis/DeltaDrone [19] and Infinium Robotics [20] combine drones with an automated ground vehicle (an AGV) with a mounted calibration board on top. The tethered (wired) drones are physically attached with a cable to a ground vehicle, which also increases battery lifetime. Therefore, the air time of such a technology is up to four hours, whereas technologies without automated ground vehicle can be up to ca. 30 minutes (e.g. inventAIRy). Yet, using wired drones reduces the hovering and maneuverability of drones and makes the integration in warehouses rather difficult.

Favorable Warehouse Characteristics

Warehouses with the following characteristics have a high potential for drones:

✓ **Relatively large size**
>10'000 square meters

✓ **Long corridors** (>50 meters)
- Long walking distances increase time needed to accomplish tasks

✓ **High shelfs** (>5 meters)
- Dangerous tasks for operators

✓ **Single deep pallet rack**
- Barcode scanning not possible for double deep storage principle

Outlook

Drones “fly high” in warehouses. We expect to see a high number of new tests and implementations of drones in warehouse operations in the next years.

This development is likely to be driven by companies in high-cost countries, but it doesn’t have to. For instance, Indian media released a news in December 2018 that the Indian Ministry of Civil Aviation has legalized the use of drones after a four year long prohibition phase [21]. In October 2014, the Director General of Civil Aviation (DGCA) had banned the use of drones due to privacy and security concerns and lack of regulation [21]. Mahindra Logistics, an Indian based logistics giant, already stated on May 19, 2019 that they are awaiting further indoor regulatory approvals before starting to use drones for inventory management [22]. That said, the legalization in India is boosting the potential for additional indoor drone applications.

Despite difficulties of intra-logistics for indoors, two big German companies have recently tested outdoor intra-logistics drone flights. ZF was the first company in Germany that received approval for the automated drone flights delivering spare parts on factory premises [23]. By the end of 2018, the first test flight was successfully accomplished. The second company, Thyssenkrupp Steel, announced in May 2019 its first on site drone delivery flight delivering laboratory samples [24]. These two recent applications are important milestones for the intra-logistics applications of drones in Europe. Although the use cases are outdoors, it shows that there is potentials for indoor experiments in the near future.

References

[1] MarketsandMarkets, "Unmanned Aerial Vehicles (UAV) market," 2019. [Online]. Available: https://www.marketsandmarkets.com/Market-Reports/unmanned-aerial-vehicles-uav-market. [Accessed: 31-May-2019].

[2] "Amazon Prime Air." [Online]. Available: https://www.amazon.com/Amazon-Prime-Air/b?ie=UTF8&node=8037720011. [Accessed: 10-Jun-2019].

[3] C. E. Palazzi, "Drone Indoor Self-Localization," 2015.

[4] L. Xu, V. R. Kamat, and C. C. Menassa, "Automatic extraction of 1D barcodes from video scans for drone-assisted inventory management in warehousing applications," *International Journal of Logistics Research and Applications*, 2018.

[5] E. Companik, M. J. Gravier, and M. T. Farris, "Feasibility of Warehouse drone adaption and implementation," *Bryant University*, 2018.

[6] C. Alias, U. Salewski, V. E. Ortiz Ruiz, F. E. Alarcón Olalla, J. do E. Neirão Reymão, and B. Noche, "Adapting Warehouse Management Systems to the Requirements of the Evolving Era of Industry 4.0," 2017.

[7] D. C. Hoffmann, "Inventory Control Drones: Business potential and best practices," *Verein Netzwerk Logistik Schweiz*, vol. 2, pp. 24–28, 2017.

[8] "Flyability," 2019. [Online]. Available: https://www.flyability.com/elios-2. [Accessed: 04-Jun-2019].

[9] "DHL TrendReport Unmanned Aerial Aircraft." [Online]. Available: https://www.dhl.com/content/dam/downloads/g0/about_us/logistics_insights/DHL_TrendReport_UAV.pdf. [Accessed: 17-Jun-2019].

[10] "Drones are taking flight indoors. Are you ready?" [Online]. Available: https://www.roboglobal.com/insights/drones-taking-flight-indoors/. [Accessed: 17-Jun-2019].

[11] "Corvus Robotics." [Online]. Available: https://www.corvus-robotics.com/. [Accessed: 20-Jun-2019].

[12] "A drone will take care of stocktaking in the future." [Online]. Available: https://www.linde-mh.com/en/technical/News-Detail_6592.html#123. [Accessed: 20-Jun-2019].

[13] "Verity Studios," 2019. [Online]. Available: https://veritystudios.com/news/wired-verity-studios-failsafe. [Accessed: 05-Jun-2019].

[14] "Leica Aibot." [Online]. Available: https://leica-geosystems.com/de-ch/products/uav-systems/copter. [Accessed: 12-Jul-2019].

[15] "Vtrus launches drones to inspect and protect your warehouses and factories." [Online]. Available: https://techcrunch.com/2018/09/06/vtrus-launches-drones-to-inspect-and-protect-your-warehouses-and-factories/. [Accessed: 18-Jun-2019].

[16] "PINC Drones." [Online]. Available: https://www.pinc.com/. [Accessed: 22-Jun-2019].

[17] "Doks. Innovation." [Online]. Available: https://www.doks-innovation.com/. [Accessed: 22-Jun-2019].

[18] "Inventory-taking drone." [Online]. Available: https://eyesee-drone.com/drone-inventoriste-hardis-group-lance-la-phase-de-test-dun-prototype-en-conditions-reelles/?lang=en. [Accessed: 07-Jun-2019].

[19] "Warehouse inventory using dronese." [Online]. Available: https://geodis.com/de-en/newsroom/press-releases/warehouse-invenotry-using-drones-geodis-and-delta-drone-have-entered-the-industrialization-production-phas-of-their-completely-automated-solution?forced=de-en. [Accessed: 09-Jun-2019].

[20] "Infinium Scan." [Online]. Available: https://www.infiniumrobotics.com/infinium-scan/. [Accessed: 12-Jun-2019].

[21] "Government of India: Office of the director general of civil aviation." [Online]. Available: http://dgca.nic.in/cars/D3X-X1.pdf. [Accessed: 21-Jun-2019].

[22] "Mahindra Logistics awaits nod to use drones in warehouses." [Online]. Available: https://www.thehindubusinessline.com/companies/mahindra-logistics-awaits-nod-to-use-drones-in-warehouses/article27163432.ece. [Accessed: 21-Jun-2019].

[23] "ZF is First in Germany to Fly Drones over Plant Premises." [Online]. Available: https://press.zf.com/press/en/releases/release_3006.html. [Accessed: 23-Jun-2019].

[24] "Erfolgreicher Demonstrationsflug." [Online]. Available: https://www.thyssenkrupp-steel.com/de/newsroom/pressemitteilungen/pressemitteilung-110848.html. [Accessed: 22-Jun-2019].

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