Autonomous drone navigation methods

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Conferința tehnico-științifică
a studenților, masteranzilor și doctoranzilor
Chișinău, Moldova
14-16 Mai, 2025

UNIVERSITATEA TEHNICĂ
A MOLDOVEI

Motivation

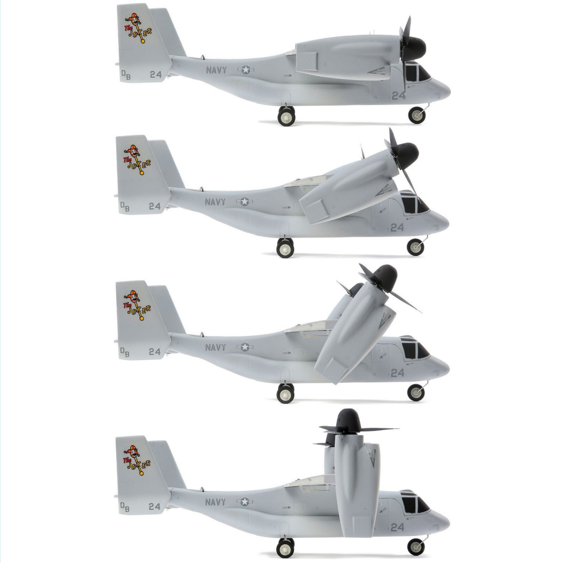
1. Drone production is on the rise
2. Drone research is on the rise
3. Drone application is diversifying[1] (agriculture, monitoring, transportation etc.)
4. Drone manufacturing shows potential for investments[2]
5. Drone navigation models differ depending on form-factor, mode of operation, application

[1] Role of Drone Technology Helping in Alleviating the COVID-19 Pandemic, https://www.mdpi.com/2072-666X/13/10/1593
[2] Global drone industry market forecasts: analysts trim their growth predictions again, https://www.unmannedairspace.info/utm-and-c-uas-market-analysis/global-drone-industry-market-forecasts-analysts-trim-their-growth-predictions-again/

Drone markets

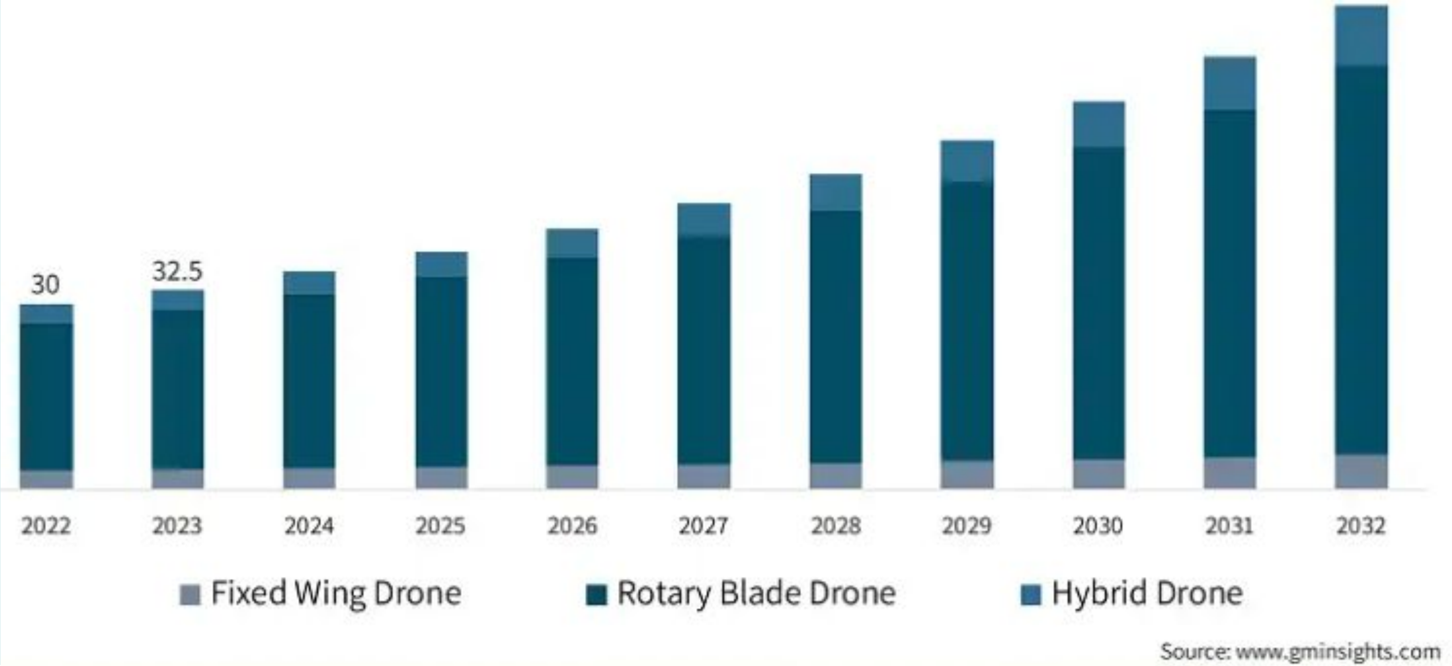
[1] Commercial Drone Market Size, Share & Trends Analysis Report By Product, https://www.grandviewresearch.com/industry-analysis/global-commercial-drones-market
[2] Commercial Drone Market - By Offering (Fixed Wing Drone, Rotary Blade Drone, Hybrid Drone), https://www.gminsights.com/industry-analysis/unmanned-aerial-vehicles-UAV-commercial-drone-market

Fixed-wing, rotary-wing, hybrid (VTOL[1]) aircraft

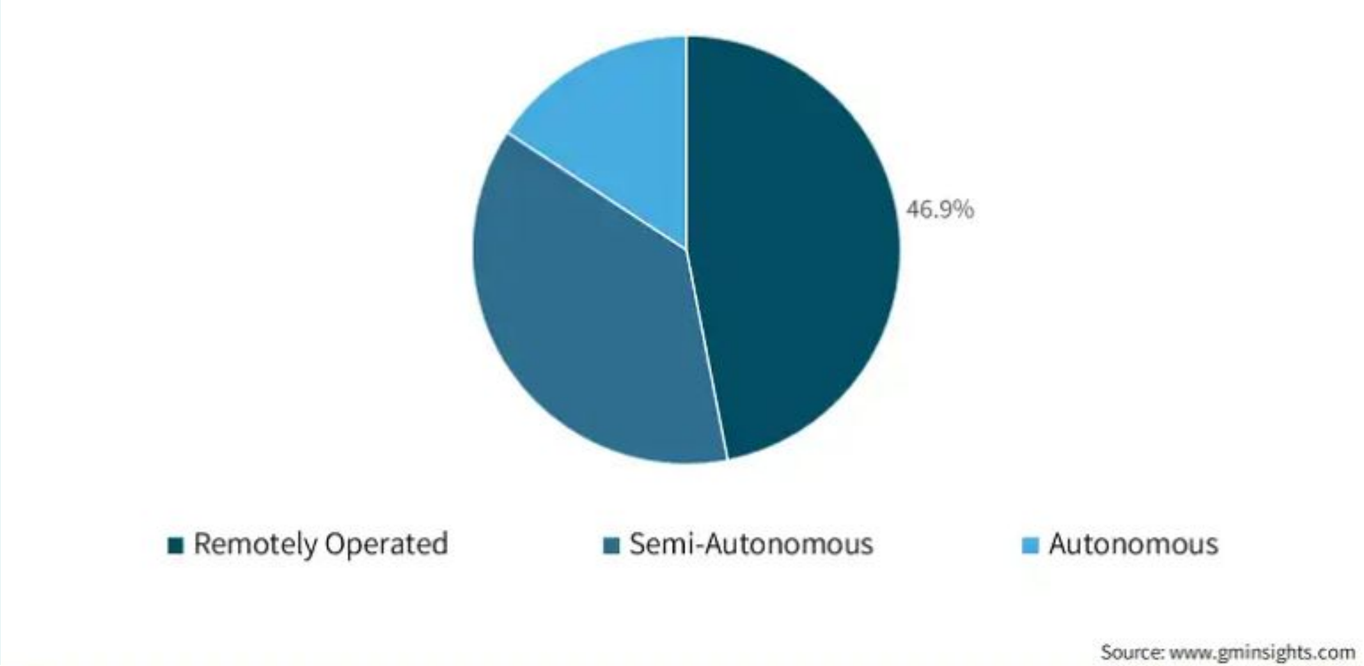


[1] Vertical Take-off and Landing (VTOL), https://www.easa.europa.eu/en/light/topics/vertical-take-and-landing-vtol

Rotary-wing form-factor dominance



Autonomous mode of operation dominance

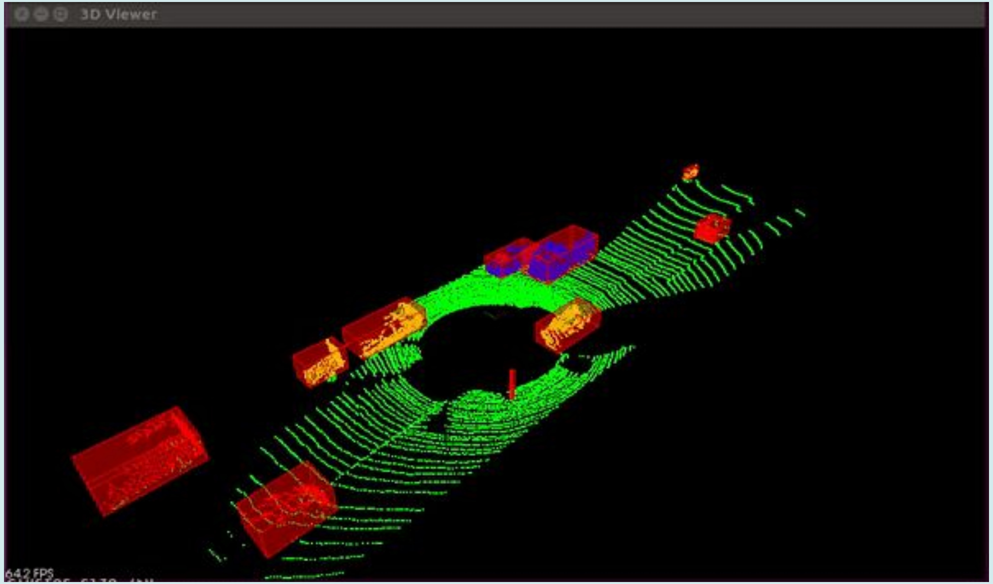


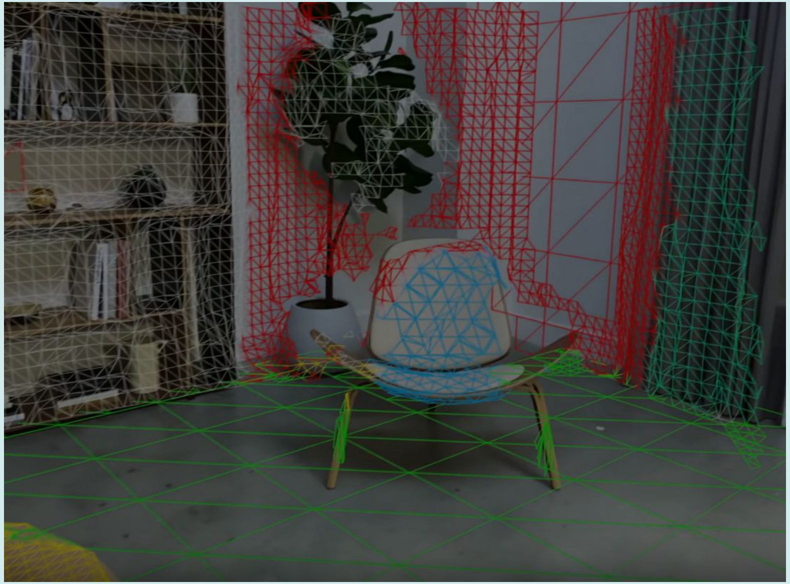
Sensors

1. LIDAR[1] (expensive);
2. Radar (susceptible to signal interference);
3. Optical (depends on image recognition technology);
4. Laser rangefinder (single-beam or sweeping, limited capability);
5. Bump (at that point it's too late).

[1] LiDAR Drone Systems: Using LiDAR Equipped UAVs, https://enterprise-insights.dji.com/blog/lidar-equipped-uavs

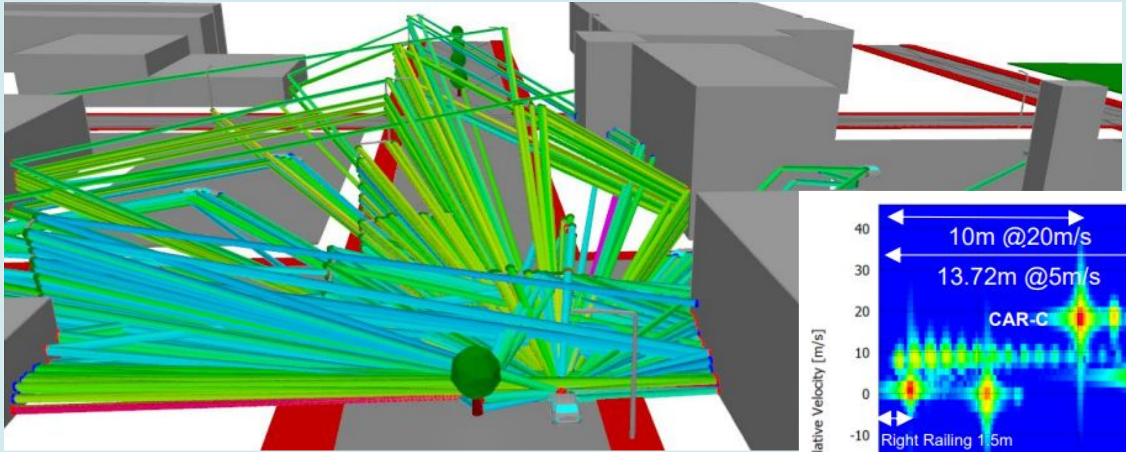
LIDAR

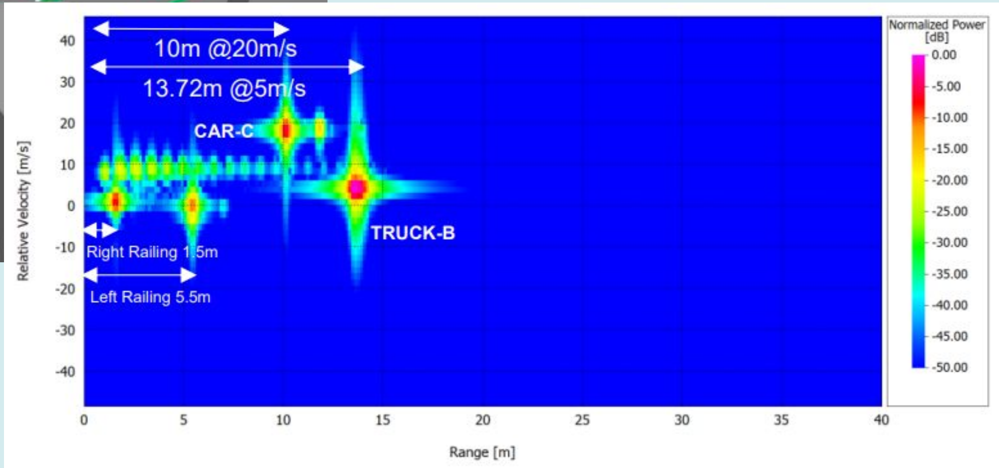




[1] Sensor-Fusion-Nanodegree, https://github.com/fanweng/Udacity-Sensor-Fusion-Nanodegree
[2] Create parametric 3D room scans with RoomPlan, https://developer.apple.com/videos/play/wwdc2022/10127/

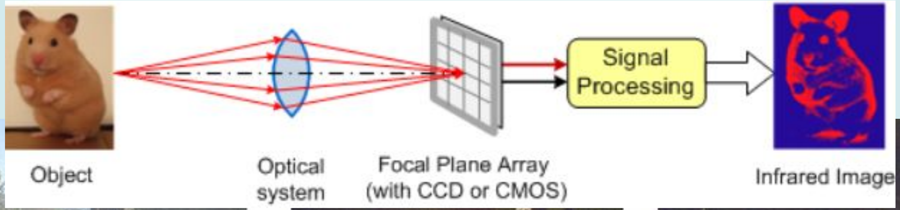
RADAR

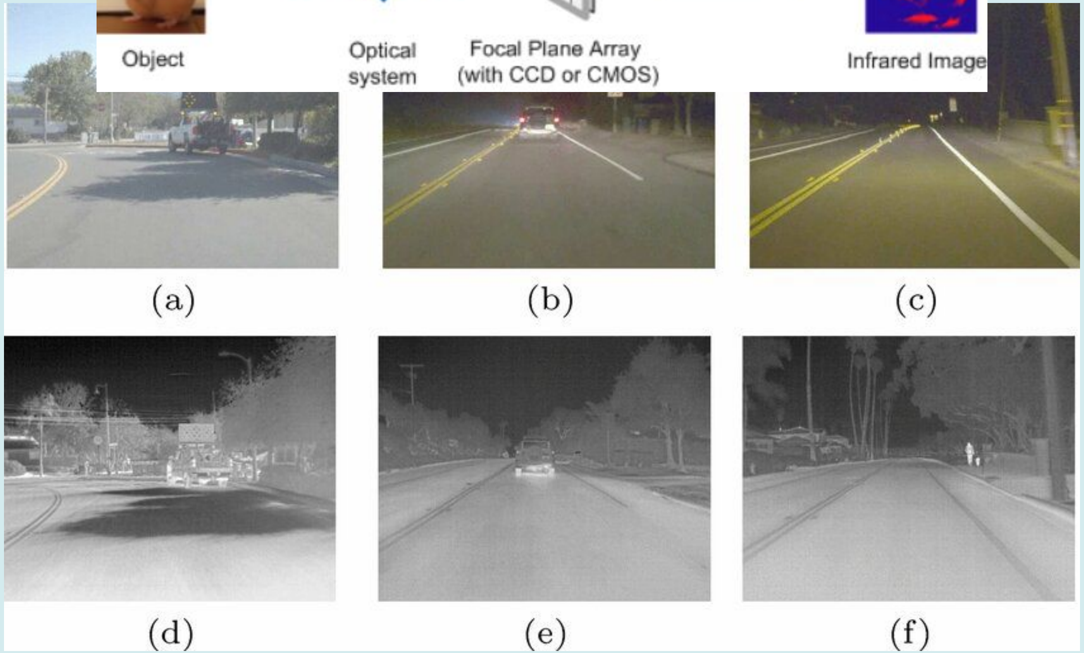




[1] Frequency Modulated Continuous Wave (FMCW) Radar for ADAS Applications, https://altair.com/resource/frequency-modulated-continuous-wave-fmcw-radar-for-adas-applications

FLIR





[1] Infrared Imaging Sensors, https://cecas.clemson.edu/cvel/auto/sensors/infrared-image.html
[2] DaCFN: divide-and-conquer fusion network for RGB-T object detection, https://link.springer.com/article/10.1007/s13042-022-01771-9

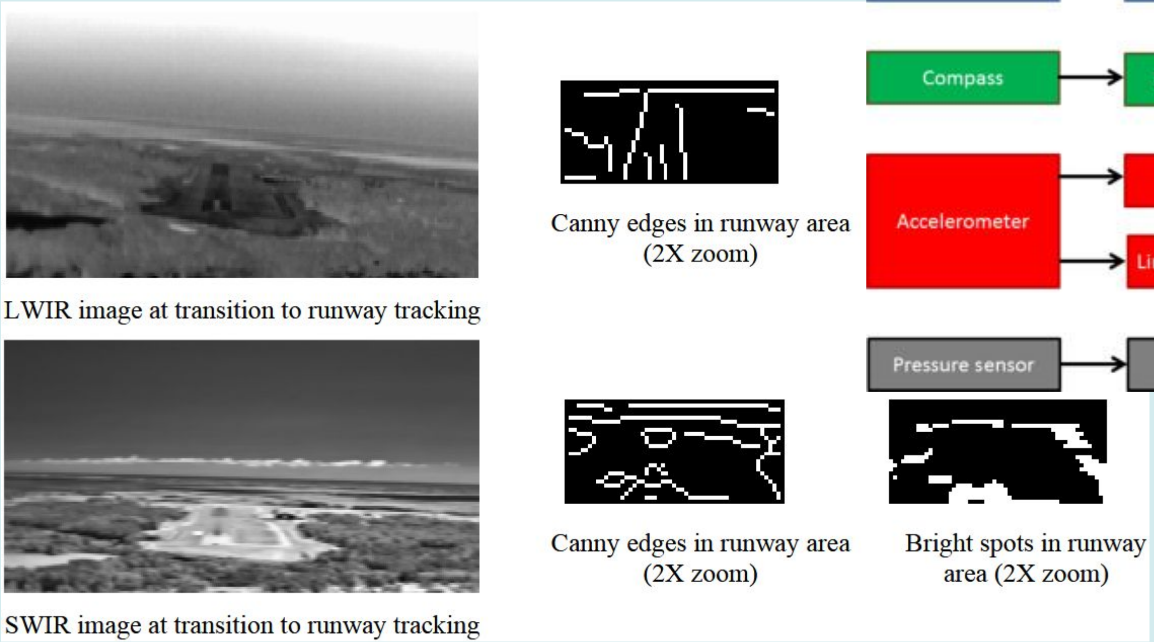
Sensing modalities comparison[1]

Pros	Pros	Pros
Best for classification/recognition	Best for capturing range + distance	Direct 3D information
AI research advanced	Day & night, adverse weatherproof	Very accurate measurements
RGB+IR for new apps, e.g., DMS/OMS	Potentially long range	AI research well advanced
High resolution, low power	Solid state, proven technology	Can be high res, works in low light

Cons	Cons	Cons
Depends on lighting/visibility	Limited classification capability	Expensive
Gets affected by shadows/reflections	Difficult to detect small objects	Ineffective in rain/fog
No direct 3D (without stereo)	AI research in the works	Mechanical parts
Gets dirty easily	Noisy	

[1] How Many Sensors For Autonomous Driving?, https://semiengineering.com/how-many-sensors-for-autonomous-driving/

Sensor fusion[1]



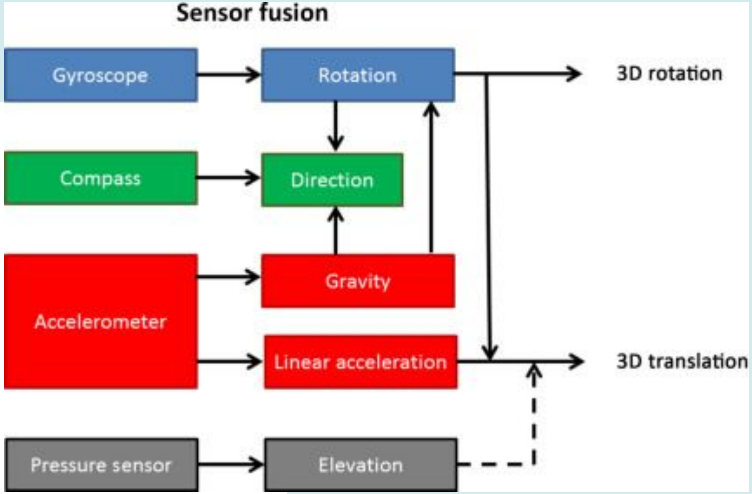
LWIR image at transition to runway tracking

Canny edges in runway area (2X zoom)

SWIR image at transition to runway tracking

Canny edges in runway area (2X zoom)

Bright spots in runway area (2X zoom)



[1] https://www.sciencedirect.com/topics/engineering/sensor-fusion
[2] Airborne FLIR sensors for runway incursion detection, https://www.researchgate.net/publication/252881980

Obstacle detection

1. Complete information about the environment
2. Incomplete information about the environment
3. Continuous data for obstacle detection
4. Discrete data for obstacle detection

Relevant stat categories

1. How data is gathered (sensor technology)
2. How data is processed (sensor fusion, image recognition algorithms)
3. How decisions are made (controllers)
4. What algorithms are used (navigation strategies)

Methodology (patent search)

1. Keyword frequency analysis
2. Ratio of academic to commercial institutions
3. Yearly trends and changes
4. No. of filed patents per institution
5. Country of filing

Problems encountered

(19) 中华人民共和国国家知识产权局

(12) 发明专利

(10) 授权公告号 CN 109029417 B
(45) 授权公告日 2021.08.10

(21) 申请号 201810489486.8

(22) 申请日 2018.05.21

(65) 同一申请的已公布的文献号
申请公布号 CN 109029417 A

(43) 申请公布日 2018.12.18

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代理人 曹芸

(51) Int.Cl.
G01C 21/00 (2006.01)
G01C 21/20 (2006.01)

(56) 对比文件
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Shaowu Yang .et al.Multi-camera visual SLAM for autonomous navigation of micro aerial vehicles.《Robotics and Autonomous Systems》.2017,第116-134页.
Foster .et al.SVO: fast semi-direct monocular visual.《IEEE International Conference on Robotics and Automation (ICRA)》.2014,第15-22页.

审查员 朱敬敬

Problems encountered (cont.)

(19) **United States**

(12) **Patent Application Publication**

ALLEN et al.

(10) **Pub. No.: US 2025/0109950 A1**

(43) **Pub. Date: Apr. 3, 2025**

(54) **SYSTEMS AND METHODS FOR NAVIGATING PATHS**

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(21) Appl. No.: **18/900,718**

(22) Filed: **Sep. 28, 2024**

Related U.S. Application Data

(60) Provisional application No. 63/587,091, filed on Sep. 30, 2023.

Publication Classification

(51) **Int. Cl.**

G01C 21/34	(2006.01)
G01C 21/36	(2006.01)
G06V 20/58	(2022.01)

(52) **U.S. Cl.**

CPC ***G01C 21/3415*** (2013.01); ***G01C 21/3691*** (2013.01); ***G06V 20/58*** (2022.01)

(57) **ABSTRACT**

In some embodiments, an electronic device navigates and/or travels using predetermined paths and/or impromptu paths. In some embodiments, the electronic device generates the impromptu paths based on characteristics, criteria, and/or factors relating to the environment of the electronic device. In some embodiments, the electronic device outputs indications of impromptu paths to be used for navigating and/or traveling.

[0028] The system further includes but not limited to:

[0029] Smart AIML Vertiport Homes

[0030] Autonomous Infrastructure

[0031] Vertiport Rail

[0032] VTOL Homes

[0033] Vertiport VTOL Parking Lots

[0034] VTOL Parking Meter

[0035] VTOL wireless charging station

[0036] VTOL storing meters

[0037] Anti-EMP

[0038] C-UAS and C-VTOL

[0039] Anti-RF

[0040] COUNTER-UAS

[0041] Non fungible and fungible tokens

[0042] on the blockchain

[0043] TIFFs

[0044] Gallium Nitride

[0045] Anti RF

[0046] DIGITAL TWINNING

[0047] AI

[0048] ML

[0049] Vertistops, Vertiportstops

[0050] vertiport university

Preliminary results

Total patents	**143**	**1**
China	82	0.5734
US	42	0.2937
S. Korea	8	0.0559
Japan	3	0.0209
Other	8	0.0559

Year of filing	**Patents**	**Year of filing**	**Patents**
2024	**5** (3)	2018	**15** (12)
2023	**22** (8)	2017	**9** (2)
2022	**22** (9)	2016	**10** (3)
2021	**18** (7)	2015	**4** (2)
2020	**13** (7)	2014	**8** (6)
2019	**16** (6)	2010	**1**

Preliminary results

Organization	No. of patents	Online
Skydio Inc.	**6**	https://www.skydio.com/
Northwestern Polytechnical University	**5**	https://en.nwpu.edu.cn/
Beihang University	**4**	https://buaa.edu.cn/
Harbin University S&T	**3**	http://www.hrbust.edu.cn/
Jilin University	**3**	https://www.jlu.edu.cn/
SZ DJI Technology Co. Ltd.	**3**	https://www.dji.com/global

Conclusions

1. Lack of uniform air traffic management
2. Lack of infrastructure
3. Lack of skilled human operators
4. Lack of comprehensive law framework (Beyond Visual Line of Sight flights etc.)