

UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

AXON ENTERPRISE, INC. AND DEDRONE HOLDINGS, INC.,
Petitioners,

v.

AIRSPACE SYSTEMS, INC.,
Patent Owner.

Case IPR2025-00525
Patent No. 10,713,959

DECLARATION OF DR. GIRISH CHOWDHARY

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I, Girish Chowdhary, hereby declare as follows:

I. INTRODUCTION & QUALIFICATIONS

1. My name is Dr. Girish Chowdhary. I make this declaration based upon my own personal knowledge and, if called upon to testify, would testify competently to the matters contained herein.

2. I have been asked to provide technical assistance in the *inter partes* review of U.S. Patent No. 10,713,959, which I may abbreviate as “the ’959 Patent” or refer to as the “Challenged Patent.” This declaration is a statement of my opinions on issues related to the unpatentability of claims of the ’959 Patent. I am being compensated at my normal hourly rate for my analysis, plus reimbursement for expenses. My compensation does not depend on the content of my opinions or the outcome of this proceeding.

3. In formulating my opinions, I have relied upon my knowledge, training, and experience in the relevant art. My qualifications are stated more fully in my curriculum vitae, which has been provided as Appendix A. My CV also lists publications on which I am a named author and identifies parties on behalf of whom I have previously provided expert testimony within the past four years. Here, I provide a brief summary of my qualifications.

4. I have over 19 years of experience with drone design and in unmanned aerial systems (“UAS”) vehicle design and autonomous control. I also have

significant experience in the design and deployment of other field robotic systems. I have designed sensor systems, control systems, guidance systems, navigation systems, and software for a variety of such vehicles, as well as led UAS autonomy design projects and other field robotics design and autonomy projects. I have also led projects related to air traffic management for UAS, including projects whose scope directly overlaps with the matters discussed in this patent.

5. I am currently an Associate Professor at the University of Illinois at Urbana Champaign in the Department of Aerospace Engineering, as well as the Department of Agricultural and Biological Engineering and Department of Computer Science. In my capacity as a professor at the University of Illinois, I founded the Distributed Autonomous Systems Laboratory, for which I am currently the Director. I also founded the Field Robotics Engineering and Sciences (FRESH) hub, for which I am the director. I am also the director of the US Department of Agriculture funded Farm of the Future, in which UAS feature prominently.

6. Prior to my position at the University of Illinois, I was an Assistant Professor at Oklahoma State University, in the School of Mechanical and Aerospace Engineering. While at Oklahoma State University, I also founded and directed their Distributed Autonomous Systems Laboratory. I led several UAS related projects at Oklahoma State University, including those funded by NASA and Air Force

Research Laboratory (AFRL). I was relied upon as an expert to contribute to projects relating to UAS Air Traffic Management.

7. In 2013, I served as a visiting professor for the Massachusetts Institute of Technology; in particular, I was a visiting professor in the Laboratory for Information and Decision Systems and for the Department of Aeronautics and Astronautics. Between 2011 and 2013, I worked at the Massachusetts Institute of Technology as a Postdoctoral Research Associate for the Laboratory for Information and Decision Systems and for the Department of Aeronautics and Astronautics. At MIT I led and contributed to several projects relating to multi-aircraft coordination, including those funded by Boeing.

8. Between 2006 and 2011, I worked at the Georgia Institute of Technology, first as a graduate research assistant, and then as a research engineer. I was employed by the School of Aerospace Engineering. I contributed to several projects funded by NASA, Air Force, and many other institutions.

9. Between 2003 and 2006 I was a Research Engineer at the German Aerospace Center (DLR). In that role I contributed to one of the first UAS projects in Germany.

10. I also have substantial industry experience. In 2016, I co-founded “Unmanned Cowboys,” a multi-product company that specializes in the commercialization of state-of-the-art UAS technologies. In 2016 I co-founded

EarthSense Inc., a company that provides autonomous drones and robots for applications in the field.

11. In 2013 through 2016, I have served as a consultant with Quarkonics Incorporated, a company that works with Fortune 500 oil and gas mining companies to create intelligent autonomous drilling techniques to improve oil well drilling.

12. From 2015 to 2016, I provided consulting services to Luminati Aerospace, a company focused on high altitude UAS.

13. Between 2008 and 2010, I was employed as a consulting controls engineer for Adaptive Flight Incorporated. In my capacity as a consulting controls engineer, I designed, developed, and tested the automation of the AFI Hornet UAS, the world's smallest commercially available UAS.

14. From 2008 to 2011, I was the team leader for the Control and Dynamics group of the Georgia Tech Aerial Robotics Team.

15. I am also the author of more than 200 publications on drone and UAS design, and am a named inventor on U.S. patents. I have been cited nearly 10,000 times for my published works in these areas.

16. I received a Bachelor of Engineering in Aerospace (with honors) from the Royal Melbourne Institute of Technology in 2003. I received my Masters in Aerospace Engineering in 2008 from the Georgia Institute of Technology, and my Ph.D. in 2010, also from the Georgia Institute of Technology. My dissertation was

on “Concurrent Learning for Convergence in Adaptive Control Without Persistency of Excitation.”

17. I was the recipient of the Air Force Young Investigator Award in 2015, and the Ward Memorial Lecture award (2015) by the Aerospace Controls and Guidance Systems Committee for outstanding contributions to adaptive control for aerospace systems.

18. I have been or am the Principle Investigator on several federally funded projects relating to aerospace systems and unmanned aerial vehicles.

19. Below is a list of some of my relevant publications

20. Borkar Aseem V, **Chowdhary G.**, Multi-Agent Aerial Monitoring of Moving Convoys using Elliptical Orbits, International Conference on Robotics and Automation (**ICRA**), XiAn China and online, June 2021.

21. Joshi Girish, Virdi Jasvir, **Chowdhary G.**, Asynchronous Deep Model Reference Adaptive Control, Conference on Robot Learning (**CORL**), Massachusetts Institute of Technology (held online due to COVID-19), MA, Nov 2020.

22. Ure N. K., **Chowdhary G.**, How J. P., Vian J., Health-Aware Planning Under Uncertainty for Collaborative Heterogeneous Teams of Mobile Agents, Unmanned Systems, Vol 3, No. 2, pp 89-107, April 2015.

23. Allamaraju R., Kingravi H., Axelrod A., **Chowdhary G.**, Grande R., How J. P., Crick C., Sheng W., Human Aware Path Planning in Urban Environments with Nonstationary MDPs, IEEE International Conference on Robotics and Automation (**ICRA**), Hong-Kong China, May 2014.

24. Kannan S., **Chowdhary G.**, Johnson E., Adaptive Control of Unmanned Aerial Vehicles – Theory and Flight Test Results, Springer handbook of UAVs, January 2014.

25. Ure N. K., **Chowdhary G.**, Toksoz T., How J. P., Vavrina M., Vian J., An Automated Battery Management System to Enable Persistent Missions with Multiple Aerial Vehicles, IEEE Transactions on Mechatronics, Vol. 20, No. 1, pp. 275-286, Jan 2014.

26. Chowdhary G., Frazzoli E., **How J.**, Lui H., Nonlinear Flight Control Techniques for Unmanned Aerial Vehicles, to appear in the Springer handbook of UAVs, January 2014.

27. How J., Frazzoli E., **Chowdhary G.**, Linear Flight Control Techniques for Unmanned Aerial Vehicles, to appear in the Springer handbook of UAVs, January 2014.

28. **Chowdhary G.**, Johnson E., Theory and Flight Test Validation of a Concurrent Learning Adaptive Controller, AIAA Journal of Guidance Control and Dynamics (JGCD), Vol. 34, No. 2, pp. 592-607, March-April 2011.

29. **Chowdhary G.**, Johnson E., Chandramohan R., Kimbrell M. S., Calise A., Guidance and Control of Airplanes Under Actuator Failures and Severe Structural Damage, AIAA Journal of Guidance Control and Dynamics (JGCD), vol 36, No. 4, pp. 1093-1104, 2013.

30. **Chowdhary G.**, Sobers M., Salün E., Ottander J., Fully Autonomous Indoor Flight Relying on Five Very Low-Cost Range Sensors, AIAA Journal of Aerospace Information Systems (JAIS), Vol 10, No. 1, pp 21-31, January 2013.

31. **Chowdhary G.**, Johnson E., Magree D., Wu D., Shein A., GPS-Denied Indoor and Outdoor Monocular Vision Aided Navigation and Control of Unmanned Aircraft, Journal of Field Robotics (JFR), Vol 30, No. 3, pp 415-438, March 2013.

32. **Chowdhary G.**, Johnson E., Adaptive Neural Network Flight Control using both Current and Stored data, Proc. of AIAA Guidance Navigation and Control Conference (GNC), NC, USA 2007.

33. **Chowdhary G.**, Sobers M., Christmann C. H., Kimbrell S. M., Johnson E., Georgia Tech Aerial Robotics Team: 2009 International Aerial Robotics Competition Entry, First Symposium on Indoor Flight Issues, University of Puerto Rico Mayagüez, PR, USA 2009, winner of best paper award.

34. Therefore, based on my education, professional experience of over 19 years, and scholarly publications, I am an expert in the relevant field of the '959 Patent and have been an expert in this field since before the '959 Patent was filed

with the United States Patent and Trademark Office (“USPTO”). I am familiar with how a person having ordinary skill in the art would have understood and used the terminology found in the ‘959 Patent at the time of filing.

II. TASK SUMMARY AND MATERIALS REVIEWED

35. I have been asked to review the Challenged Patent and its prosecution history, to provide an understanding of the technology relevant to the Challenged Patent, to review certain prior-art references, and analyze whether or not those references disclose or teach limitations of claims from the Challenged Patent. The opinions stated in this declaration are from the perspective of a person of ordinary skill in the art (POSITA).

III. LIST OF EXHIBITS

36. In forming my opinions, I have reviewed the Challenged Patent, its prosecution history and references cited by the Examiner, the materials cited in the List of Exhibits, and the materials cited throughout my declaration.

Ex.	Description
1001	U.S. Patent No. 10,713,959 to Foina <i>et al.</i> , “Low Altitude Aircraft Identification System” (the “’959 Patent”)
1002	File History for U.S. Patent No. 10,713,959
1003	Declaration of Dr. Girish Chowdhary
1004	Complaint for Patent Infringement, <i>Airspace Systems, Inc. v. Dedrone Holdings, Inc.</i> , Case No. 1-24-cv-01625 (E.D. VA), September 16, 2024

1005	U.S. Patent No. 10,192,451 to Foina <i>et al.</i> , “Low Altitude Aircraft Identification System,” (the “451 Patent”) filed December 12, 2017
1006	International Publication No. WO2016/201359 A1 filed on June 10, 2016 as International Application No. PCT/US/2016037071 (the “071 Application”)
1007	U.S. Provisional Application No. 62/173,153 to Foina <i>et al.</i> , “A low altitude aircraft identification system” (the “153 Provisional”), filed June 12, 2015
1008	U.S. Patent No. 10,733,894 to Beard <i>et al.</i> , “Direct-Broadcast Remote Identification (RID) Device for Unmanned Aircraft Systems (UAS),” (“Beard”) filed February 26, 2018 and issued August 4, 2020
1009	U.S. Provisional Application No. 62/480,031 to Beard, “Remote Identification” (“Beard Provisional”), filed March 31, 2017
1010	U.S. Patent Application Publication No. 2016/0253907 to Taveira, “Systems and Method for Restricting Drone Airspace Access,” (“Taveira”) filed January 29, 2015 and published September 1, 2016
1011	International Publication No. WO2016/078093 A1 to Wang <i>et al.</i> , “System and Method for Managing Unmanned Aerial Vehicles,” (“Wang”) filed November 21, 2014 and published May 26, 2016
1012	International Publication No. WO2016/154949 A1 to Gong <i>et al.</i> , “Authentication Systems and Methods for Generating Flight Regulations,” (“Gong”) filed March 31, 2015 and published October 6, 2016
1013	U.S. Patent Application Publication No. 2016/0127890 to Qi <i>et al.</i> , “Apparatus, System and Method of Protecting a Service Identifier,” (“Qi”) filed December 24, 2014 and published May 5, 2016
1014	International Publication No. WO2015/043123 A1 to Wang <i>et al.</i> , “Data Communication Systems and Methods,” (“Wang-IP”) filed January 14, 2014 and published April 2, 2015
1015	Claim Listing of Challenged Claim
1016	File History for U.S. Patent No. 10,192,451

1017	First Amended Complaint for Patent Infringement, <i>Airspace Systems, Inc. v. Dedrone Holdings, Inc.</i> , Case No. 1-24-cv-01625 (E.D. VA), October 30, 2024
1018	Airspace Systems, Inc.’s Opposition to Defendants’ Rule 12(b)(6) Motion to Dismiss, <i>Airspace Systems, Inc. v. Dedrone Holdings, Inc.</i> , Case No. 1-24-cv-01625 (E.D. VA), January 13, 2025
1019	U.S. Patent Application Publication No. 2014/0337633 <i>et al.</i> , “System and Method for Indicating a Service Set Identifier,” filed May 7, 2014 and published November 13, 2014
1020	U.S. Patent Application Publication No. 2006/0236376 to Liu <i>et al.</i> , “Wireless Security Using Media Access Control Address Filtering with User Interface,” filed April 1, 2005 and published October 19, 2006
1021	Kayton, Myron and Fried, Walter, <i>Avionics Navigation Systems</i> , John Wiley and Sons, 1997.

IV. SUMMARY OF CONCLUSIONS AND GROUNDS FOR CHALLENGE

37. After reviewing the materials identified in the List of Exhibits, I have concluded that each of the Challenged Claims of the ‘959 Patent would have been obvious to a person of ordinary skill in the art, based on the following grounds.

Ground	‘959 Claims	Basis for Challenge
1	21	Obvious over <i>Beard</i>
2	21	Obvious over <i>Taveira</i> in view of <i>Wang</i> and <i>Gong</i>
3	21	Obvious over <i>Taveira</i> in view of <i>Qi</i> and <i>Gong</i>

4	21	Obvious over <i>Gong</i> in view of <i>Wang-II</i>
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V. LEGAL STANDARDS

A. LEVEL OF ORDINARY SKILL IN THE ART

38. When interpreting a patent, I understand that it is important to identify the relevant art pertaining to the patent-in-suit as well as the level of ordinary skill in that art at the time of the claimed invention. The “art” is the field of technology to which the patent is related.

39. I have been instructed by counsel that the person of ordinary skill in the art (“**POSITA**”) is a hypothetical person who is presumed to know the relevant prior art. I understand that the actual inventor’s skill is not determinative of the level of ordinary skill. I further understand that the factors that may be considered in determining the level of skill include: the types of problems encountered in the art; prior art solutions to those problems; rapidity with which innovations are made; sophistication of the technology; and educational level of active workers in the field. I understand that not all such factors may be present in every case, and one or more of them may predominate.

B. LEGAL STANDARD FOR CLAIM CONSTRUCTION

40. I understand that the first step in determining whether a patent claim would have been anticipated or obvious is to ascertain how a POSITA would have understood the claim terms.

41. I have been instructed by counsel on the law regarding claim construction and patent claims, and I understand that a patent may include two types of claims: independent claims and dependent claims. An independent claim stands alone and includes only the limitations it recites. A dependent claim can depend from an independent claim, or it can further depend from another dependent claim. I understand that a dependent claim includes all the limitations that it recites, in addition to all the limitations recited in the claim(s) from which it depends.

42. It is my understanding that in proceedings before the USPTO, the claims of a patent are to be construed under what is referred to as the “Phillips standard.” I understand that this means that claim terms of a patent are given the meaning the terms would have to a POSITA, in view of the description provided in the patent itself and the patent’s file history.

43. I understand that to determine how a person of ordinary skill would understand a claim term, one should look to those sources available that show what a person of skill in the art would have understood the disputed claim language to mean. I understand that, in construing a claim term, one looks primarily to the

intrinsic patent evidence, including the words of the claims themselves, the remainder of the patent, and the patent's prosecution history. I understand that extrinsic evidence, which is evidence external to the patent and the prosecution history, may also be useful in interpreting patent claims when the intrinsic evidence itself is insufficient.

44. I understand that words or terms should be given their ordinary and accepted meaning unless it appears that the inventors were using them to mean something else. In making this determination, the claims, the remainder of the patent, and the prosecution history are of paramount importance. Additionally, the patent and its prosecution history must be consulted to confirm whether the patentee has acted as its own lexicographer (i.e., provided its own special meaning to any disputed terms), or intentionally disclaimed, disavowed, or surrendered any claim scope.

45. In comparing the claims of the Challenged Patent to the prior art, I have considered the Challenged Patent and its file history in light of the understanding of a person of skill at the time of the alleged invention.

C. ANTICIPATION

46. It is my understanding that the claims of a patent are anticipated by a prior art reference if each and every element of the claim is found either explicitly or inherently in a single prior art reference or system. I understand that inherency

requires a showing that the missing descriptive matter in the claim is necessarily or implicitly present in the allegedly anticipating reference, and that it would have been so recognized by a POSITA. In addition, I understand that an enabling disclosure is a disclosure that allows a POSITA to make the invention without undue experimentation. Although anticipation typically involves the analysis of a single prior art reference, I understand that additional references may be used to show that the primary reference has enabling disclosure, to explain the meaning of a term used in the primary reference, and/or to show that a characteristic is inherent in the primary reference.

D. OBVIOUSNESS

47. I understand that the prior art may render a patent claim “obvious.” I understand that two or more prior art references (e.g., prior art articles, patents, or publications) that each disclose fewer than all elements of a patent claim may nevertheless be combined to render a patent claim obvious if the combination of the prior art collectively discloses all elements of the claim and one of ordinary skill in the art at the time would have been motivated to combine the prior art in such a way. I understand that this motivation to combine need not be explicit in any of the prior art, but may be inferred from the knowledge of one of ordinary skill in the art at the time the patent was filed. I also understand that one of ordinary skill in the art is not an automaton, but is a person having ordinary creativity. I further understand that

one or more prior art references, articles, patents or publications that disclose fewer than all of the elements of a patent claim may render a patent claim obvious if including the missing element would have been obvious to one of skill in the art (e.g., the missing element represents only an insubstantial difference over the prior art or a reconfiguration of a known system).

48. I understand that under the doctrine of obviousness, a claim may be invalid if the differences between the invention and the prior art are such that the subject matter as a whole would have been obvious at the time the invention was made to a POSITA to which the subject matter pertains.

49. To assess obviousness, I understand that I am to consider the scope and content of the prior art, the differences between the prior art and the claim, the level of ordinary skill in the art, and any secondary considerations to the extent they exist.

50. I understand that any evidence of secondary indicia of non-obviousness should be considered when evaluating whether a claimed invention would have been obvious to one of ordinary skill at the time of invention. These secondary indicia of non-obviousness may include, for example:

- a long felt but unmet need in the prior art that was satisfied by the claimed invention;
- commercial success of processes claimed by the patent;
- unexpected results achieved by the invention;
- praise of the invention by others skilled in the art;

- the taking of licenses under the patent by others; and
- deliberate copying of the invention.

51. I understand that there must be a nexus between any such secondary indicia and the claimed invention.

52. It is also my understanding that there are additional considerations that may be used as further guidance as to when the above factors will result in a finding that a claim is obvious, including the following:

- the claimed subject matter is simply a combination of prior art elements according to known methods to yield predictable results;
- the claimed subject matter is a simple substitution of one known element for another to obtain predictable results;
- the claimed subject matter uses known techniques to improve similar devices or methods in the same way;
- the claimed subject matter applies a known technique to a known device or method that is ready for improvement to yield predictable results;
- the claimed subject matter would have been “obvious to try” choosing from a finite number of identified, predictable solutions, with a reasonable expectation of success;
- there is known work in one field of endeavor that may prompt variations of it for use in either the same field or a different one based on design incentives or other market forces if the variations would have been predictable to a POSITA;
- there existed at the time of the invention a known problem for which there was an obvious solution encompassed by the patent’s claims; and

- there is some teaching, suggestion, or motivation in the prior art that would have led a POSITA to modify the prior art reference or to combine prior art reference teachings to arrive at the claimed subject matter.

53. Finally, I understand that a claim may be deemed invalid for obviousness in light of a single prior art reference, without the need to combine references, if the elements of the claim that are not found in the reference can be supplied by the knowledge or common sense of one of ordinary skill in the relevant art.

E. PRIORITY DATE

54. I understand that, subject to the next paragraph, the asserted “priority date” of a patent is the earlier of: (a) the date on which a patent application is filed; or (b) the date on which an earlier-filed patent application is filed if the patentee claims the benefit of priority to that earlier-filed patent application.

55. I understand that it is not enough for a patent to merely claim the benefit of an earlier-filed application, but that additional criteria must be met. In particular, the prior application itself must describe the claimed invention, and must do so in sufficient detail that one skilled in the art can clearly conclude that the inventor invented the claimed invention as of the filing date sought. First, I understand that a priority-date analysis is on a claim-by-claim basis. Second, I understand that, in order for a patent claim to be entitled to the filing date of an earlier patent application, a “Section 112 analysis” must be conducted. I am informed that a “Section 112”

analysis encompasses looking to the earlier patent application, and ascertaining whether that earlier patent application meets both the written-description and enablement requirements as of the filing date of the earlier application. I understand that it is not enough that the claim would have been obvious from the earlier application, but that application itself must describe the claimed invention.

56. I understand that in order to satisfy the written description requirement the earlier application must reasonably convey to those skilled in the art that the inventors had possession of the subject matter of the patent as of the filing date of the earlier application. I have been informed that it is the disclosures of the earlier patent application that count, and that while the meaning of terms, phrases, or diagrams in the earlier patent application must be interpreted from the vantage point of one skilled in the art, all of the claimed limitations must appear in the specification. Further, I understand that this analysis is not a question of whether one skilled in the art might be able to construct the claimed invention from the teachings of the disclosure. The question is not whether a claimed invention is an obvious variant of that which is disclosed in the specification; rather, I understand that an earlier application must itself describe each of the claim limitations.

57. I also understand that in order to satisfy the enablement requirement, the earlier application must enable a person of ordinary skill in the art to practice the claimed invention without undue experimentation.

VI. OVERVIEW OF THE CHALLENGED PATENT

58. I have reviewed U.S. Patent No. 10,713,959 (“the ’959 Patent”), which is entitled “Low Altitude Aircraft Identification System.” I understand that the patent was filed on December 10, 2018, and that it was issued on July 14, 2020. The ’959 Patent claims priority to Provisional application No. 62/175,153 filed on June 12, 2015 and to Provisional application No. 62/566,450 filed on October 1, 2017. Ex. 1001, item (60).

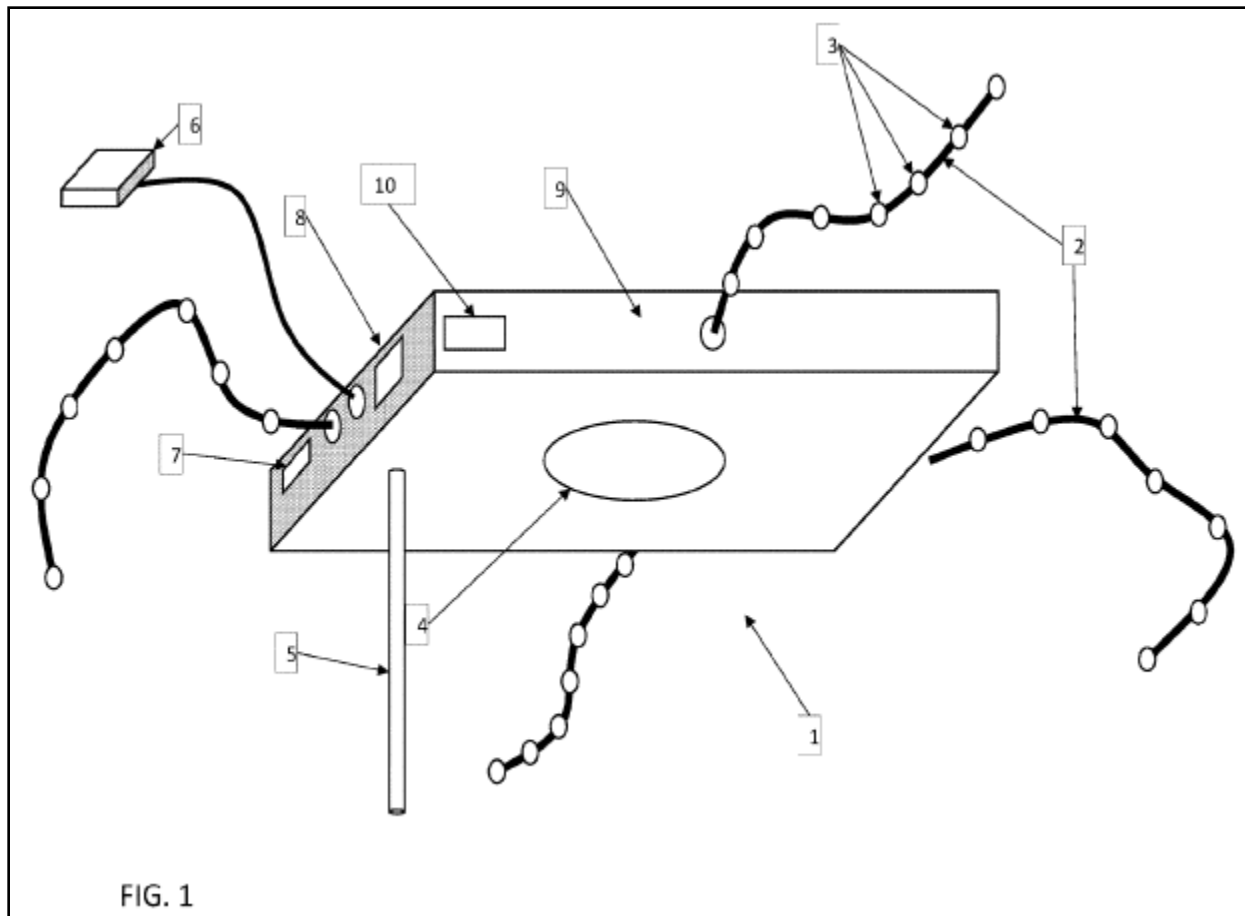
A. THE SUBJECT MATTER OF THE CHALLENGED PATENT

59. The ’959 Patent generally relates to “a low altitude aircraft identification system composed by three components: a small aircraft electronic identification box with an embedded logger, a ground identification equipment to automatically identify the aircraft just pointing at it, and an identification code database.” Ex. 1001, Abstract. The ’959 Patent identifies a “drone” as an example of a “low altitude aircraft” (*id.*, 12:61-62), and generally explains that its disclosed system is directed to solve issues related to identifying “unmanned aerial vehicles (UAVs) or unmanned aircraft systems (UASs)” and similar devices (*id.*, 1:35-2:3).

60. The ’959 Patent explains that the electronic identification box generates an “identification code” that is used to identify the aircraft associated with the electronic identification box, and that the identification code effectively operates as a “license plate” for the aircraft. *Id.*, 2:18-67. The identification code is

implemented in two embodiments—“a visible light color sequence or by a radio frequency signal”—both of which are recognized by the ground identification device. *Id.*, 2:14-17.

61. When the identification code is implemented as a color pattern sequence, the electronic identification box uses a “light array” to “blink[] a defined color pattern sequence for each aircraft” such that the code is visually identifiable by an observer. *Id.*, 2:30-36. Figure 1 of the ’959 Patent, copied below, depicts identification box 1, which “includes one or more light arrays 2 each including several light color emitters 3,” which “generate (e.g., blink, variable light intensity or color fade) a defined color sequence programmed” for the associated aircraft. Ex. 1001, 5:5-11.

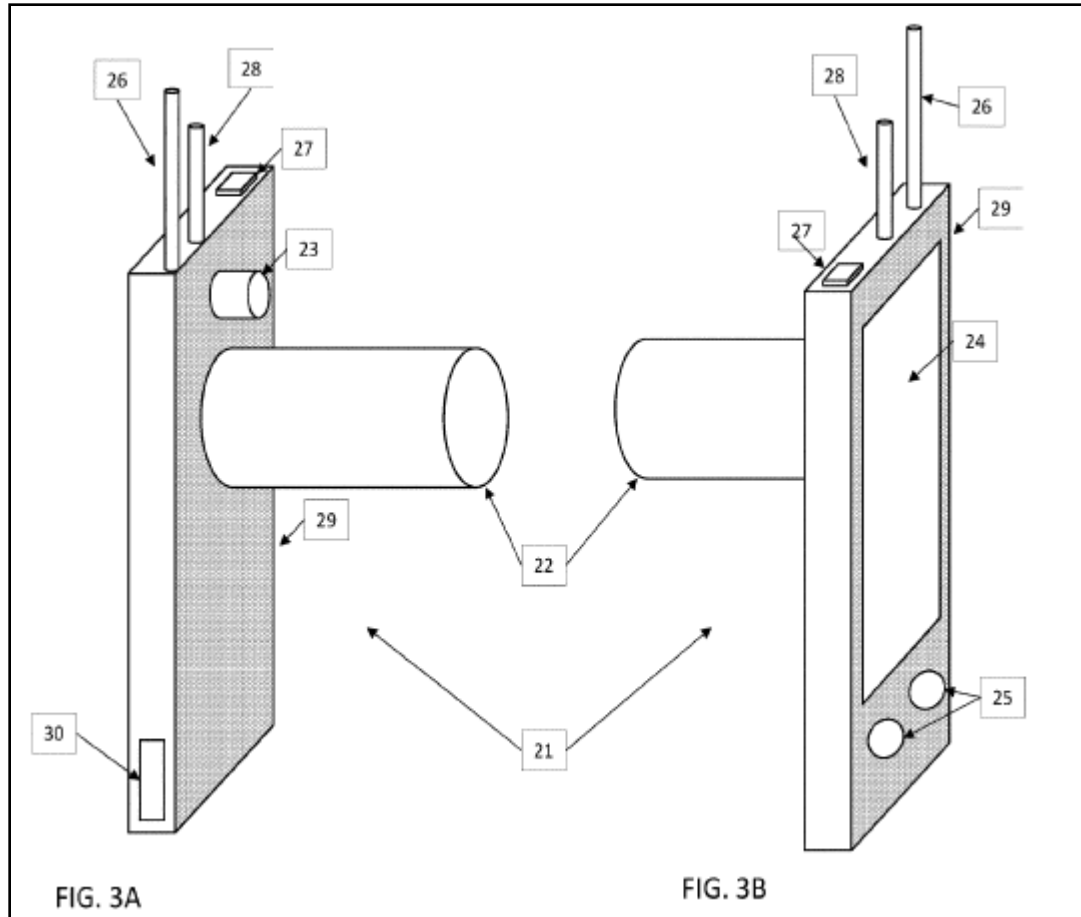


Ex. 1001, Fig. 1.

62. When the identification code is implemented as a radio frequency signal, the '959 Patent explains that a “transponder” included in the electronic identification box “may transmit a code similar to the one generated (e.g., blinked) by the light arrays but through the RF frequency, allowing automatic identification by any RF receiver on land, or installed in other aircraft.” *Id.*, 2:56-59.

63. The '959 Patent further describes the “Ground Identification Device,” explaining that it is a “remote (e.g., ground) device” that is used to “assist the aircraft identification.” *Id.*, 3:28-38. “[T]he ground device is equipped with a camera, lens

and image processing algorithms to capture the color sequence” generated by the identification box, and the ground device has an RF receiver capable of receiving the identification box RF signal.” *Id.*, 3:39-43. Upon detecting an aircraft and checking the aircraft’s identification code, the ground device may display on its screen information about the aircraft, such as whether “the aircraft position and time stamp is according to its permitted flight plan.” *Id.*, 3:47-62. Figures 3A and 3B, copied below, depict the ground device:



Id., Figs. 3A, 3B.

64. Further, the '959 Patent describes using an “SSID” or “Service Set Identifier,” which “utilized to address information packets over wireless networks.” *Id.*, 4:41-42, 11:20-22. The '959 Patent explains that its system “implements a rotating SSID,” whereby the SSID used to identify packets sent by an identification box are “frequently chang[ed],” which “greatly reduce[s]” the probability of the SSID “being discovered or spoofed.” *Id.*, 11:20-24.

65. Claims 1-20 of the '959 Patent incorporate elements related to both the light array and radio frequency embodiments; these claims are not challenged in this Petition. *See, e.g.*, Ex. 1001, 15:53-65 (“A device configured to communicate identification information associated with a low-altitude aircraft, the device comprising: one or more light arrays each including color light emitters that generate a defined color sequence...; a radio frequency communication antenna coupled to a radio communication module that transmits information associated with the low-altitude aircraft through a transmitted radio signal...”). Claim 21—the only challenged claim—relates only to the radio frequency embodiment. *See id.*, 17:17-18:17.

B. THE CHALLENGED CLAIMS OF THE ‘959 PATENT

66. The Challenged Claim of the '959 Patent, Claim 21, is set forth below.

#	Limitation
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21[p]	A device configured to communicate identification information associated with a low-altitude aircraft, the device comprising:
21[a]	a radio frequency communication antenna;
21[b]	a radio communication module coupled to the radio frequency communication antenna and configured to transmit identification information associated with the low-altitude aircraft through a transmitted radio signal,
21[c]	wherein the radio communication module is configured to receive a received radio signal and store the information in a storage,
21[d]	wherein the radio frequency communication antenna is coupled to the low-altitude aircraft and
21[e]	the radio communication module is configured to utilize a secure identifier,
21[f]	and the radio communication module is configured for two-way communication with a remote portable detection system;
21[g]	and wherein the device is coupled to the low-altitude aircraft and
21[h]	the remote portable detection system includes a user interface configured to provide to a user, information associated with a plurality of different low-altitude aircrafts detected by the remote portable detection system.

C. PROSECUTION HISTORY OF THE ‘959 PATENT

67. The application leading to the ‘959 Patent was filed on December 10, 2018, as U.S. Application 16/215,406 (the “’406 Application”). Ex. 1001, items (21), (22). On its face, the ‘959 Patent purports to be a “[c]ontinuation of application No. 15/839,661, filed on Dec. 12, 2017, now Pat. No. 10,192,451 [(the “’451 Patent,” Ex. 1005)], which is a continuation of application No. PCT/US2016/037071 [(the “’071 Application,” Ex. 1006)] filed on Jun. 10, 2016.” *Id.*, item (63). The

'959 Patent claims priority to provisional application No. 62/175,153 (the "'153 Provisional," Ex. 1007), which was filed on June 12, 2015, and provisional application No. 62/566,450, which was filed on October 1, 2017. *Id.*, item (60).

68. The Patent Office issued a first Non-Final Office Action on August 7, 2019, rejecting Claims 1-20¹ on the ground of nonstatutory double patenting based on claims 1-20 of U.S. Patent No. 10,192,451. Ex. 1002, 114. As noted above, the '959 Patent discloses two primary mechanisms for generating and transmitting its "identification code": (1) through a visible light sequence (*e.g.*, as generated by a light array) and (2) as a radio frequency (RF) signal. *See supra*, VI.A. The examiner's prior art search history, however, indicates that the examiner's primary focus was on the visible light embodiment (which, as discussed above, is captured in Claims 1-20, but not Claim 21, *see supra*, VI.A), as nearly all of the examiner's search queries directed to the subject matter of the application (as opposed to searches directed to related patent numbers, relevant priority dates, or inventors) include the term "light" or "color." *See* Ex. 1002, 138-142 (showing only subject matter searches S7 and S8 as not including the terms "light" or "color"). And the

¹ Claim 21 was originally numbered as Claim 20 before being corrected during prosecution. *See* Ex. 1002, 40-41 (5/28/202 Notice of Allowance detailing examiner's amendment to correct claim numbering).

only two subject matter searches that do not include the terms “light or “color” are directed to generic search terms that would apply to all claims (*e.g.*, “drone or UAV or UAS” and “communicate and antenna and sensor”), and not Claim 21 specifically. *See id.*

69. On February 7, 2020, the applicant filed a terminal disclaimer to obviate the double patenting rejection. *Id.*, 98. On March 25, 2020, the Patent Office issued a notice of allowance. *Id.*, 61.

D. PRIORITY DATE OF THE ‘959 PATENT

70. It is my opinion that Challenged Claim 21 is entitled to claim priority no earlier than October 1, 2017, because Claim 21 is not entitled to claim priority to either the ’153 Provisional or the ’071 Application.

1. Claim 21 is not entitled to claim priority to the ’153 Provisional.

71. The ’959 Patent’s priority claim to the ’153 Provisional, which was filed on June 12, 2015, must be disregarded because the ’153 Provisional does not provide adequate written description for the limitation “*the radio communication module is configured to utilize a secure identifier*” recited in Claim 21. That is because the ’153 Provisional contains no disclosure of a “secure identifier,” let alone any disclosure of using a “secure identifier” as claimed.

72. As an initial matter, the ’153 Provisional does not use the term “identifier” at all. *See generally* Ex. 1007. Instead, the ’153 Provisional discloses

the use of an “identification code” that is used by an unmanned aerial vehicle (UAV) or unmanned aircraft system (UAS) to identify itself. *Id.*, 9-10, 16. The ’153 Provisional teaches that an “electronic identification box” associated with the UAV/UAS communicates the identification code in two formats: (1) “a unique color pattern sequence for each aircraft” as generated by a blinking light array and/or (2) a “code” that is transmitted through an “RF frequency similar to the one generated (e.g., blinked) by the light arrays.” *Id.* The color pattern and/or the code are then transmitted from the electronic identification box on the UAV/UAS to a “ground identification device,” which then transmits this information “to a server through a data communication antenna 28 connected to a data communication module 38 (e.g. cellular network or Wi-Fi).” *Id.*, 9-11, 13.

73. To the extent the “identification codes” and associated device identities may be considered “identifiers,” which I do not concede, the ’153 Provisional fails to describe the use of a “secure identifier,” as there is no discussion by the ’153 Provisional of “securing” anything, let alone “identifiers.” In fact, the ’153 Provisional suggests that its identification codes are *not* secure, as the ’153 Provisional teaches that comprehending the identifiers is achieved simply by looking at the correct UAV/UAS (when the identification code is a light sequence) or receiving the correct radio frequency (when the identification code is a code transmitted in an RF signal). *Id.* When implementing the identification code as a

light sequence, for example, the '153 Provisional acknowledges that “*any person* can visually identify an aircraft in a low altitude flight.” *Id.*, 15 (emphasis added). Similarly, there is no discussion of “securing” the identification information when it is transmitted from the ground identification device to the server. *See id.*, 13.

74. The '153 Provisional provides no discussion of securing the identification codes (*e.g.*, by using encryption) or any other piece of information. Accordingly, the '153 Provisional does not provide written description support of Claim 21's recitation of “the radio communication module is configured to utilize a secure identifier,” so Claim 21 is not entitled to the '153 Provisional's June 12, 2015 priority date.

2. The '959 Patent is not entitled to claim priority to the '071 Application.

a) Claim 21 is not entitled to claim priority to the '071 Application.

75. The '959 Patent's priority claim to the '071 Application must be disregarded because the “secure identifier” subject matter of Claim 21 was not disclosed in the '071 Application for the same reasons discussed above with reference to the '153 Provisional. That is, like the '153 Provisional, the '071 Application:

- does not use the term “identifier” at all (*see generally* Ex. 1006);

- merely discloses the use of an “identification code” implemented as either a color pattern or a code transmitted via RF signals (*id.*, [7]-[17]);
- includes no discussion of “securing” anything, let alone identifiers, and even suggests that the disclosed identification codes (to the extent these are interpreted as “identifiers,” which Petitioners do not concede) are *not* secure (*see* Ex. 1006, [9] (explaining that when the identification code is implemented as a color pattern, “a person [can] visually identify an aircraft from a distance of about 500 feet, without the use of any special equipment”). *See also supra*, VI.D.1.

76. In contrast, the ’959 Patent, as well as the ’451 Patent to which the ’959 Patent claims priority, discloses the use of “SSIDs conforming to the 802.11 standard as the mechanism of network packet identification.” Ex. 1001, 11:17-20; *see also* Ex. 1005, 11:10-12. The ’959 and ’451 Patents explain that the disclosed system “implements a rotating SSID which is utilized to address information packets over wireless networks. By frequently changing the SSID, the probability of it being discovered and exploited or spoofed are greatly reduced.” Ex. 1001, 11:20-24; *see also* Ex. 1005, 11:12-17. According to the ’959 and ’451 Patents, using SSIDs in such a rotating manner improves the security of communications between devices, as it addresses the risk of malicious actors determining the current SSID, “cloning” a device associated with the SSID, and intercepting packets intended for the device.

Ex. 1001, 1:56-65; *see also* Ex. 1005, 1:48-57. The '959 and '451 Patents each dedicate more than a column of text to detail the design and implementation of the rotating SSID scheme. Ex. 1001, 11:5-12:17; *see also* Ex. 1005, 10:64-12:10.

77. Thus, the '071 Application provides no discussion of securing the identification codes (*e.g.*, by using encryption) or any other piece of information, nor does it discuss a “rotating SSID” as disclosed by the '959 and '451 Patents. Accordingly, the '071 Application does not provide written description support of Claim 21's recitation of “the radio communication module is configured to utilize a secure identifier,” so Claim 21 is not entitled to the '071 Application's June 10, 2016 priority date.

78. Because the '153 Provisional and the '071 Application lack adequate support for the “secure identifier” limitation recited in Claim 21 of the '959 Patent and the earliest possible priority date for this claim is October 1, 2017, the filing date of U.S. Provisional Application No. 62/566,450, to which the '959 and '451 Patents claim priority.²

VII. LEVEL OF ORDINARY SKILL IN THE ART

79. A person of ordinary skill in the art would have either (1) a Bachelor of Science in Mechanical Engineering, Electrical Engineering, Aerospace Engineering,

² While I apply the priority date of U.S. Provisional Application No. 62/566,450, I do not concede that it supports the SSID-related disclosures of the '959 and '451 Patents.

or an equivalent field as well as at least 2 years of academic or industry experience in the aerospace, avionics, telecommunications, or electronics device manufacturing industry , or (2) at least four years of industry experience in any of the above.

VIII. CLAIM CONSTRUCTION

80. It is my opinion that a POSITA would understand all the claim terms to have their plain and ordinary meaning, and I have applied the plain and ordinary meaning, in the context of the '959 Patent, for all claim terms.

IX. TECHNOLOGY BACKGROUND AND STATE OF THE ART

81. In the subsections below, I describe some of the basic principles of engineering that would have been used, or at least considered for use, in the design and production of aerospace and/or avionics systems. The principles discussed in the subsections below would have been well-known to a POSITA in the 2015 timeframe, and long before. Several of the facts discussed below can be found in standard textbooks, such as *Avionics Navigation Systems* by Kayton and Fried, John Wiley and Sons, 1997 (Ex. 1021).

A. RADIO TRANSMISSIONS AND ANTENNAE.

82. Radio Frequency transmission is a preferred method of communicating with aircraft, and in particular Unmanned Aerial Systems (UAS). This is because these aircraft are flying in the air, and as such it is not possible to ensure that a physical connection with a cable can be established with them. Therefore, the only

mechanisms of communication that are feasible will require some form of over-the-air transmission. There are only three primary ways in which this can be done:

- a. Radio Frequency: The only reasonable and commonly used way to communicate with remote devices without a wire or wirelessly is using radio communication. In this method signals are transcribed in non-visible spectrum electromagnetic radiation and transmitted using an antenna. An antenna is inherently required for any kind of radio frequency communication. Various different part of the electromagnetic spectra are used for radio frequency communication. In the US for example, LTE operates on 600 MHz, 700 MHz, 850 MHz, 1700/2100 MHz, 1900 MHz, and 2500 MHz bands. There are several benefits to using electromagnetic radiation that is not in the visible spectrum. Non-visual spectrum electromagnetic radiation, such as radio waves, enables long-distance transmission, better penetration through obstacles, and reduced scattering compared to the visible light spectrum.
- b. Visible spectrum signals: This includes sending signals as visible spectrum light, which can then be perceived by a visual light sensor, such as a cameras or human eyes. This method is often preferred when communicating with humans or animals since they natively perceive

visual spectrum electromagnetic radiation, also referred to as “light”. However, it is not a preferred method for communicating with UAS or other aircraft due to its line of sight dependency, limited ability to penetrate obstacles (e.g., clouds, fog, and physical barriers), high susceptibility to scattering and atmospheric interference, and the need for precise alignment between the transmitter and receiver. These limitations make it less reliable than radio frequency (RF) communication, which offers greater range, obstacle penetration, and robustness in diverse environments.

- c. Audio signals: Also referred to as sonar, this method requires receivers on both ends that can capture audio signal. This method is heavily limited in its range, and is clearly not a good choice for any kind of sustained communication with a UAS.

83. In summary, an antenna is an indispensable part of a UAS because it facilitates the transmission and reception of electromagnetic signals, enabling essential functions such as remote control, telemetry, data transfer, and communication with other systems. Antennas ensure efficient coupling of radio frequency (RF) energy to the medium (air), support reliable long-range communication, and allow integration with various frequency bands for navigation (e.g., GPS), payload data, and command-and-control links critical to UAS

operations. Without antennas, these communication and navigation capabilities would be significantly impaired.

84. Therefore, a POSITA would find it obvious to consider that a UAS is equipped with an antenna. *See generally* Ex. 1021, Chapter 4 (pp. 99-177).

B. AIR TRAFFIC MANAGEMENT AND ITS HISTORY WITH RESPECT TO UAS

85. Air Traffic Management System refers to mechanisms, apparatus, and protocols for ensuring that multiple aircraft can fly safely in the same airspace. Unlike ships, which travel on surface, aircraft travel at different altitudes. It is harder to establish a clear line of sight with aircraft due to clouds, fog, glare, or obstacles. Therefore, visual spectrum methods such as light-houses, signal flags, semaphore, Morse code with light (Aldis Lamp), or other colored lights or patterns are not practical for aircraft. Hence radio frequency-based Air Traffic Management has been an integral part of the growth of the aviation industry. *See generally*, Ex. 1021, Chapter 14 (pp. 642-690). A brief history is below.

1. Early Radio Communication (1920s–1940s):

86. **Initial Adoption:** Radio technology was introduced to aviation in the 1920s, allowing air traffic controllers to communicate directly with pilots instead of relying on visual signals or written messages.

87. **Frequency Allocation:** Early systems used AM (amplitude modulation) frequencies, which were susceptible to interference and eavesdropping.

88. **Need for Secure Channels:** The rapid growth in air traffic during World War II emphasized the importance of reliable and secure communication to avoid collisions and ensure national security.

2. Post-War Developments (1940s–1960s):

89. **Standardization:** ICAO established global standards for aviation radio frequencies in the **VHF (Very High Frequency) band**, typically 118–137 MHz.

90. **Improved Reliability:** VHF offered clearer communication and less interference than AM, and rapidly emerged as the preferred method.

91. **Emerging Security Needs:** Cold War-era aviation brought heightened concerns about unauthorized interception of communications, highlighting the need for secure radio channels.

3. Advent of Automation and Data Links (1970s–1990s):

92. **Secondary Surveillance Radar (SSR):** Introduced transponders to communicate with radar stations, providing automatic aircraft identification.

93. **Data Link Communication:** Systems like CPDLC (Controller-Pilot Data Link Communications) began supplementing voice communication, reducing reliance on congested radio channels.

94. **Encryption:** Although voice channels remained unencrypted, secure systems for data links started emerging to protect sensitive information from interception.

4. Modernization and ADS-B (2000s–Present):

95. **Satellite Navigation and Surveillance:** Automatic Dependent Surveillance–Broadcast (ADS-B) uses radio frequencies to broadcast aircraft position, altitude, and velocity. However, these broadcasts are unencrypted, raising concerns about spoofing and interception.

96. **Frequency Congestion:** The increasing demand for spectrum by modern systems such as ADS-B and UAS traffic management (UTM) requires careful regulation and secure management to prevent interference.

C. RADIO FREQUENCY COMMUNICATION AND SECURITY CHALLENGES

97. From its inception, radio frequency communication in aviation has been pivotal for ensuring safe operations. Frequencies in the VHF (Very High Frequency) range were adopted to reduce interference and improve clarity. Despite these advancements, early systems lacked encryption, leaving them vulnerable to interception and unauthorized use. The reliance on open channels for voice communication between air traffic controllers and pilots persisted as a legacy feature, even as digital systems began to supplement traditional methods.

98. The introduction of data link communications, such as Controller-Pilot Data Link Communications (CPDLC), provided a partial solution by enabling encrypted exchanges for critical information. Similarly, advancements in cybersecurity and spectrum management have sought to protect the integrity of

communication systems. Nevertheless, technologies like ADS-B continue to operate without encryption, illustrating the tension between accessibility, operational simplicity, and security in aviation systems. Although it should be noted that military versions of ADS-B have used encryption to ensure security.

D. INTEGRATION OF UAS INTO AIRSPACE MANAGEMENT HAVE OBVIOUSLY REQUIRED RADIO FREQUENCY COMMUNICATION AND ENCRYPTION

99. Unmanned Aircraft Systems (UAS) have introduced new complexities to airspace management. Unlike manned aircraft, which operate within well-established ATM frameworks, UAS often function at low altitudes and in urban environments, where traditional radar and transponder-based systems are impractical. In addition, the number of these aircraft in a single unit of airspace could be significantly higher than commercial aviation aircraft. This is because UAS are designed to be small, and often also designed for short duration missions. This would lead to unprecedented congestion of small units of air space. Furthermore, due to their low-flying nature, occlusions are commonplace.

100. Therefore, a POSITA would have been naturally motivated to consider using radio frequency for communication with UAS. This would have included using transponders with antenna and computers that would transmit signals of interest between UAS and ground control stations. In addition, given the very high number of UASs in any given unit of airspace, and the potential for spoofing,

confusion, and other issues, as POSITA would have been naturally motivated to use encryption or other secure channels.

101. The principles underpinning Remote ID are analogous to longstanding practices in ATM, particularly those associated with ADS-B and transponder-based identification. The broadcast of identification and positional information via radio frequencies is not a novel concept; rather, it represents an adaptation of established technologies to meet the unique requirements of UAS. Additionally, the need for secure communication in Remote ID systems reflects a broader aviation priority to mitigate risks associated with unauthorized access, spoofing, and interference.

X. OVERVIEW OF THE PRIOR ART

A. BEARD (EX. 1008)

1. Status of Beard

102. “*Beard*” is a United States filed February 26, 2018, as App. No. 15/905,340 and issued on August 4, 2020. *Beard* claims priority to U.S. Provisional Application No. 62/480,031 filed March 31, 2017 (Ex. 1009, “*Beard Provisional*”). The filing date of the *Buckley Provisional* is before the October 1, 2017 priority date of Claim 21 of the ’959 Patent, which is the earliest priority data to which I believe Claim 21 of the ’959 Patent is entitled. The portions of *Beard* on which I rely are supported by *Beard Provisional*.

2. Overview of the Disclosure of *Beard* and *Beard Provisional*

103. Like the '959 Patent, *Beard* describes a “remote identification (RID) device attachable to an unmanned aircraft system (UAS) [that] encodes identifier signals based on a unique identifier of the UAS and position data, e.g., the current and originating (launch) positions of the UAS, and transmits encoded data signals receivable and decodable by specially configured receiver devices in range.” Ex. 1008, Abstract; Ex. 1009, 3 (describing overall functionality of RID device), 7-8, 11 (describing use of “digital signature” to secure communications against spoofing). Thus, *Beard* is from the same field of art as the '959 Patent and describes an identification device that is similar to the device described in the '959 Patent.

B. *TAVEIRA* (EX. 1010)

1. Status of *Taveira*

104. “*Taveira*” is a U.S. Patent Application Publication filed on January 29, 2015, which is before the earliest possible priority date of Claim 21 of the '959 Patent.

2. Overview of the Disclosure of *Taveira*

105. *Taveira* describes “drone 100” that has a “control unit 110” that includes “a processor 120, a radio module 130, and a power module 150.” Ex. 1010, [0054]. *Taveira* explains that “the processor of the drone 100 may provide drone information,” such as “a drone identifier, a drone access level, drone payment information, drone authorization credentials, and/or other information” to “an access

server 240” (Ex. 1010, [0110]) or a “beacon device” (*id.*, [0117]). *Taveira* explains that the drone identifier can be a “unique identifier (ID)” that “may allow the drone to be identified by network components, such as servers..., beacons..., other drones, and so on.” *Id.*, [0168]. Thus, *Taveira* is from the same field of art as the ’959 Patent and describes an identification device that is similar to the device described in the ’959 Patent.

C. WANG(Ex. 1011)

1. Status of Wang

106. “*Wang*” is an international application published under the Patent Cooperation Treaty filed on November 21, 2014, which is before the earliest possible priority date of Claim 21 of the ’959 Patent.

2. Overview of the Disclosure of Wang

107. *Wang* discloses that wireless communications between a base station 300 and a UAV 201 are encrypted, and that “suitable encryption methods” include “SSID hiding” and “MAC ID filtering.” Ex. 1011, [0160], Fig. 1. Thus, *Wang* is in a field of art—encrypting wireless communications between a UAV and remote device—that is highly relevant to the ’959 Patent, which describes securing wireless communications between a drone/UAV and other device, and a person of ordinary skill in the art (POSITA) would understand that *Wang* addresses the potential problem of unsecured wireless communications involving a drone/UAV.

D. GONG(Ex. 1012)**1. Status of Gong**

108. “*Gong*” is an international application published under the Patent Cooperation Treaty filed on March 31, 2015, which is before the earliest possible priority date of Claim 21 of the ’959 Patent.

2. Overview of the Disclosure of Gong

109. *Gong* discloses a UAV that includes a “flight control unit,” such as “flight control unit 410,” which comprises “identification module 410, one or more processors 420, and one or more communication modules 430.” Ex. 1012, [0233], [0235]. “The identification module may be able to uniquely identify and differentiate the UAV from other UAVs,” and “may comprise a UAV identifier and a key of the UAV.” *Id.*, [0236]. *Gong* explains that the “UAV identifier may be unique to the UAV” and “may uniquely differentiate and/or distinguish the UAV from other UAVs.” *Id.*, [0133]. Further, the “UAV may broadcast the UAV identifier during operation.” *Id.*, [0277]. Thus, *Gong* is highly relevant to the ’959 Patent, as it describes a system for identifying a drone/UAV to external devices, as is taught by the ’959 Patent.

E. Qi (EX. 1013)**1. Status of Qi**

110. “*Qi*” is a U.S. Patent Application Publication published on filed on December 24, 2014, which is before the earliest possible priority date of Claim 21 of the ’959 Patent.

2. Overview of the Disclosure of Qi

111. *Qi* teaches a system for periodically updating an SSID used in wireless communications. Ex. 1013, [0168]-[0169]. *Qi* explains that “updating the SSID, e.g., along time, may increase the security of the SSID and/or may reduce the probability of an attacker to discover the service name of the service based on the SSID, e.g., compared to an implementation in which the SSID is kept constant.” Id., [0170]. Thus, *Qi* is in a field of art—updating SSIDs used in wireless communications to improve the security of those communications—that is highly relevant to the ’959 Patent, which describes rotating SSIDs over time to reduce the likelihood of discovery and tampering by other parties.

F. WANG-II (EX. 1014)**1. Status of Wang-II**

112. “*Wang-II*” is an international application published under the Patent Cooperation Treaty filed on January 14, 2014, which is before the earliest possible priority date of Claim 21 of the ’959 Patent.

2. Overview of the Disclosure of *Wang-II*

113. *Wang-II* discloses a “communication terminal 1200” capable of bi-directional wireless communication that “includes an uplink receiver 1204, a downlink transmitter 1202, and an antenna 1206.” Ex. 1014, [00141].

XI. GROUND 1: BEARD ANTICIPATES CLAIM 21

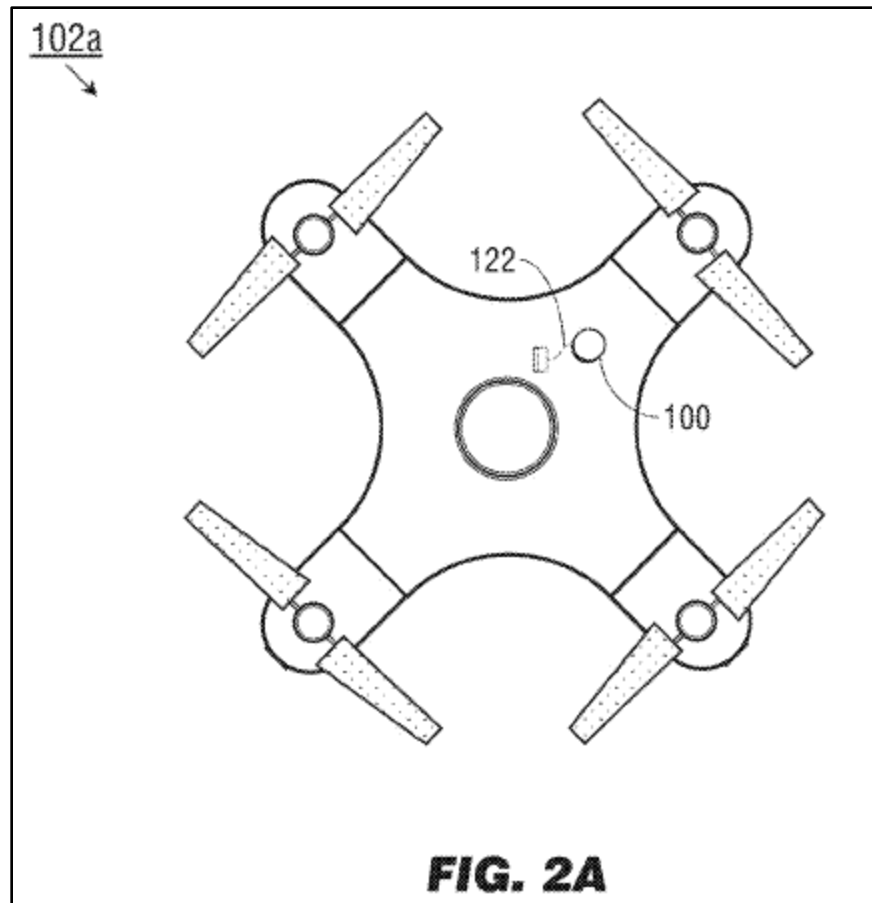
A. CLAIM 21

1. 21[p]: A device configured to communicate identification information associated with a low-altitude aircraft, the device comprising:

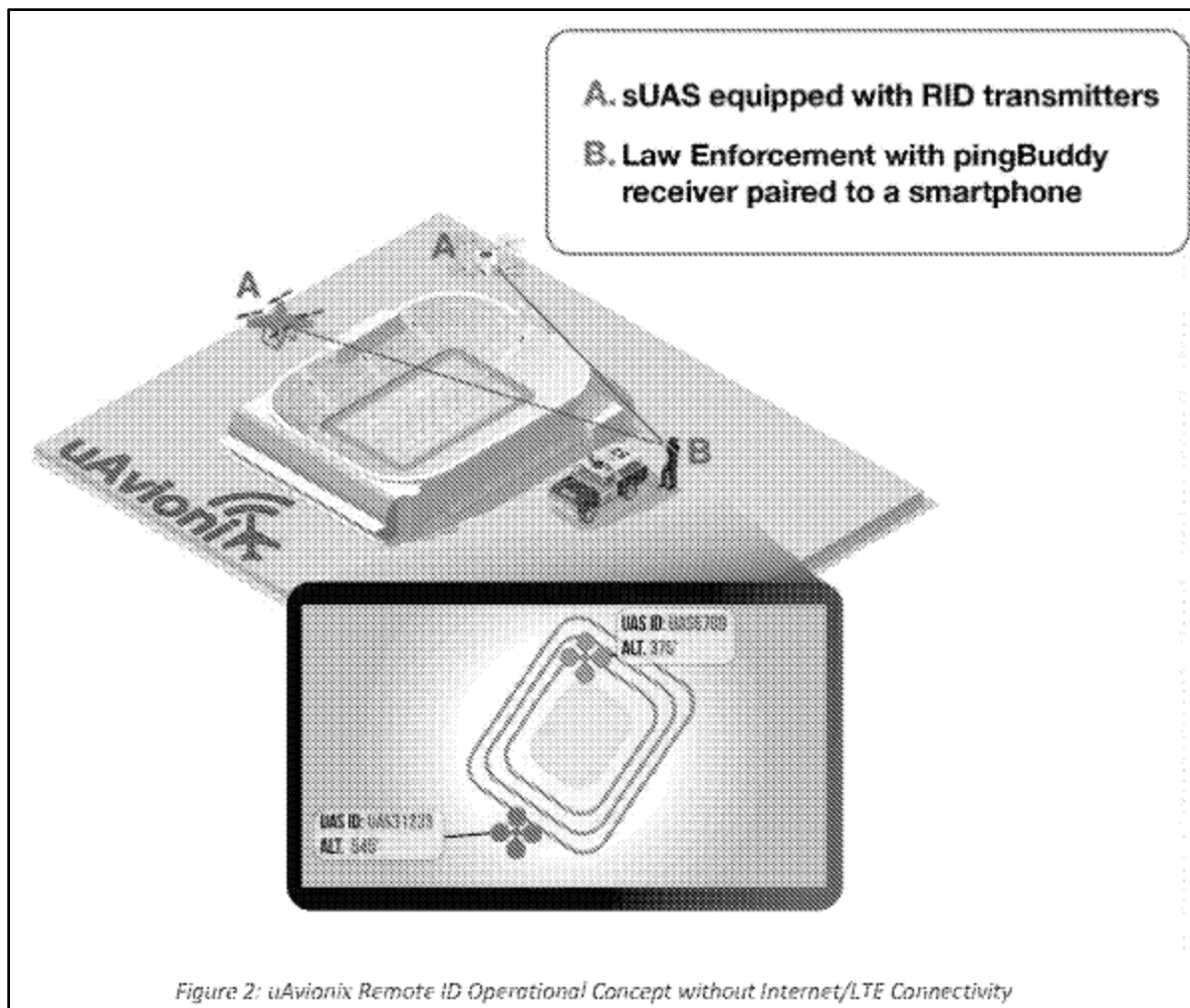
114. To the extent the preamble is limiting, *Beard* discloses the preamble through its description of a remote identification (RID) device that communicates information that identifies an associated unmanned aircraft system (UAS). *Beard* describes “a direct-broadcast remote identification (RID) device attachable to an unmanned aircraft system (UAS) encodes identifier signals based on a unique identifier of the UAS and position data, e.g., the current and originating (launch) positions of the UAS, and transmits encoded data signals receivable and decodable by specially configured receiver devices in range.” Ex. 1008, Abstract; *see also id.*, 4:61-5:7; Ex. 1009, 3 (“The primary purpose of the RID solution is for law enforcement or security personnel to remotely identify the sUAS aircraft and operator through a number of key parameters to be transmitted from an RID transmitter onboard the sUAS and received by receivers which may be handheld, permanently mounted, onboard other aircraft, or anywhere within range of the RID

transmitter. ... Data items transmitted from the sUAS RID would include at a minimum the FAA UAS registration number and sUAS position. This concept is not unlike a license plate on a vehicle or an N-Number on an aircraft... Considerations for anti-spoofing or source verification should be included.”), 4 (“Airborne RID transmitter which broadcasts sUAS position and operator identifying data.”).

115. Further, *Beard*’s “UASs” are “low-altitude aircraft.” First, *Beard* explains that its device is directed to solving the challenge of “[r]egulating the operations of drones, rotorcraft, multicopters, and other unmanned aircraft systems (UAS; also small UAS, or sUAS),” and generally depicts the UASs as drones, all of which are devices well-known to be “low altitude aircraft.” Ex. 1008, 2:22-23; Ex. 1009, 2 (describing development of “components for sUAS communications, navigation, and surveillance (CNS)”).



Ex. 1008, Fig. 2A (depicting UAS 102a as a 4-rotor drone); *see also id.*, Fig. 3



Ex. 1009, Figure 2 (depicting “sUAS equipped with RID transmitters” as 4-rotor drones); *see also id.*, Fig. 3. This understanding of *Beard*’s UASs as “low altitude aircraft” is consistent with the ’959 Patent, which acknowledges that a “drone” is an example of a “low altitude aircraft.” *See* Ex. 1001, 12:61-62.

116. Second, *Beard* explains that its system interfaces with “unified threat management (UTM) providers (150; e.g., PrecisionHawk Low Altitude Tracking and Avoidance System (LATAS),” which further shows that *low altitude aircraft* are subject to *Beard*’s system. Ex. 1008, 9:35-44, Fig. 5A; Ex. 1009, 6 (“If in an

internet available environment, additional features in the app would provide more information such as registration and flight plan data through integration with the FAA registration database and/or UTM-like applications such as PrecisionHawk's LATAS or AirMap platforms.”).

117. Accordingly, *Beard*'s RID device, which communicates identification information associated with drones, rotorcrafts, and multicoptors (*low altitude aircraft*) teaches the preamble.

2. 21[a]: a radio frequency communication antenna;

118. *Beard* discloses, or at least renders obvious, “a radio frequency communication antenna” through its disclosure of its RID device using various radio frequency ranges for wireless communication. In particular, *Beard* provides that its RID device may use for wireless communications “[d]esignated ADS-B frequencies, e.g., 978 MHz (Universal Access Transceiver, or UAT), 1090 MHz (Extended Squitter, or ES), and 1104 MHz,” (Ex. 1008, 6:23-25; Ex. 1009, 2 (describing operation “within the ADS-B and Mode A/C/S protected aviation spectrum frequencies))), and “[s]elected frequencies within the United States industrial, scientific, and medical (ISM) radio bands, e.g., 315 MHz, 433 MHz, and 915 MHz (generally associated with garage-door openers, keyless entry systems, and cordless landline telephones respectively)” (Ex. 1008, 6:56-60; Ex. 1009, 2 (describing operation “in open industrial, scientific, and medical (ISM) radio bands applicable

in the US and internationally.’’). A POSITA would have understood that to communicate across these radio frequencies, *Beard*’s RID device would comprise an antenna (“*a radio frequency communication antenna*”) capable of transmitting and receiving signals on these radio frequencies, because antennas were well-known components in radio communications that convert electric current into radio waves (and vice versa) allowing for such communications. Accordingly, *Beard* teaches “*a radio frequency communication antenna.*”

119. In the alternative, it would have been obvious to a POSITA that *Beard*’s RID device comprises an antenna element capable of transmitting and receiving signals on ADS-B and ISM radio bands in view of *Beard*’s disclosure of communicating on those bands, as an antenna element would have been an obvious component available to a POSITA for performing such communications. As just noted, antennas were well-known components in radio communications that convert electric current into radio waves (and vice versa), allowing for radio communications. For example, antennas were also used on Unmanned Aerial Vehicles due to the need for remote control, so a POSITA would have been very familiar with implementing such a component. Thus, it would have been obvious to a POSITA that any device communicating using radio bands would have comprised an antenna capable of transmitting and/or receiving radio waves on those bands.

Accordingly, “*a radio frequency communication antenna*” is also rendered obvious by *Beard*. *Id.*

3. 21[b]: a radio communication module coupled to the radio frequency communication antenna and configured to transmit identification information associated with the low-altitude aircraft through a transmitted radio signal,

120. *Beard* teaches this element at least through its disclosure of a “radio frequency (RF) transceiver” that transmits UAS identification information. As discussed above with reference to Limitation 21[a], *Beard* discloses that its RID device utilizes various radio bands to communicate. Ex. 1008, 6:23-25, 6:56-60; Ex. 1009, 2; *supra*, XI.A.1. *Beard* further discloses “an RF transceiver,” which is the component that performs wireless communication for the RID device. Ex. 1008, 3:9-19; Ex. 1009, 2 (describing the RID device as comprising “a custom-build software defined radio,” and being a “core” of the disclosed “receive/transmit (Rx/Tx) radio products”), 9 (noting that the “RID Hardware” comprises “transmitters and receivers”), 11 (“The RID product in its base form will include the following: . . . 10mW (suggested) Transmit/Receive radio on TBD frequency.”).³

³ A POSITA would have understood that *Beard Provisional*’s disclosure of “transmitters and receivers” that make up the “RID hardware” teaches *Beard*’s “transceiver,” because a “transceiver” is a “transmitter/receiver” component of radios.

Accordingly, *Beard*'s "RF transceiver" discloses "*a radio communication module*" that is "*configured to transmit...through a transmitted radio signal.*"

121. As discussed above with reference to Limitation 21[a], *Beard* discloses, or at least renders obvious, "*the radio frequency communication antenna*" in view of *Beard*'s disclosures regarding communicating wirelessly over various radio frequency bands. *See supra*, XI.A.2. It would have been obvious to a POSITA that *Beard*'s RF transceiver ("*radio communication module*") is "*coupled to*" the antenna to fulfil the RF transceiver's role in performing wireless communication for the RID device. As discussed above, antennas were well-known components that convert electric currents to radio waves (and vice versa) and would have been electrically connected to a transceiver's transmitter and receiver elements to facilitate radio communication. As also discussed above, antennas were already part of Unmanned Aerial Vehicles in other contexts, since they are used for remote control of such vehicles, and also involved in receiving status messages or data from such vehicles to a remote operator or a monitoring station. Thus, it would have been obvious that a transceiver element would be coupled to an antenna element to facilitate the transceiver's transmit and receive functions. Accordingly, *Beard* renders obvious "*a radio communication module coupled to the radio frequency communication antenna.*"

122. Further, *Beard* teaches that its RF transceiver is “configured to transmit identification information associated with the low-altitude aircraft” at least through its disclosure of the transceiver transmitting identification data that identifies an associated UAS via an identifier signal. *Beard* teaches that transceiver 110 “may include processors . . . for encoding direct-broadcast identifier signals based on the current position of the UAS 102 and identification data stored to memory (106) when the RID device 100 is configured for use with a particular UAS. The stored identification data, analogous to a tail number, N-number or International Civil Aviation Organization (ICAO) address for manned aircraft, uniquely identifies the UAS 102 to any receivers (120) equipped to receive and decode transmitted identifier signals.” Ex. 1008, 5:33-51; Ex. 1009, 3 (disclosing that the sUAS RID device transmits “[d]ata items” that include “the FAA UAS registration number and sUAS position,” which are used to “remotely identify the sUAS aircraft and operator”). Because *Beard*’s “identification data” identifies a UAS to any receivers, the identification data discloses “identification information associated with the low-altitude aircraft.” Accordingly, *Beard* teaches Limitation 21[b].

4. 21[c]: wherein the radio communication module is configured to receive a received radio signal and store the information in a storage.

123. *Beard* discloses, or at least renders obvious, Limitation 21[c] at least through its disclosure of receiving and storing identifier signals from other UASs and storing its own identification data.

124. *Beard* explains that its RF transceiver (i.e., “radio communication module,” see *supra*, XI.A.3) can “‘listen’ for other proximate UAS within range, receiving identifier signals transmitted by another RID device (100a) aboard the proximate UAS and relaying the received signals throughout the RID coverage area of the RID device 100,” which “increase[es] the effective range of the receiver device 120” by exposing the receiver device 120 to identifier signals that are normally outside of its range. Ex. 1008, 7:34-42; Ex. 1009, 14 (describing that the RID device “is both a transmitter and a receiver” that performs “two way communications,” where the device can “act as a ‘repeater’ for other RID devices which may be out of range of a ground receiver,” where “[s]ignals from each RID device would be intelligently rebroadcast by other airborne RID devices, extending the effective range of any ground based receiver by leveraging the airborne receivers as repeaters.”). And as discussed above with reference to Limitations 21[a]-[b], *Beard* discloses that its RID devices can communicate on different radio frequencies.

See supra, XI.A.2-3. Accordingly, *Beard* teaches a “radio communication module [that] is configured to receive a received radio signal.”

125. Further, *Beard* teaches “*stor[ing] the information in a storage.*” First, to the extent “*the information*” is interpreted to refer to the “*identification information associated with the low-altitude aircraft*” recited in Limitation 21[b],⁴ *Beard* discloses that its RID device can “store[] to memory” the “current position of the UAS 102 and identification data” of the UAS associated with the RID device. Ex. 1008, 5:44-46; *see also id.*, 7:45-47 (“the memory 106 of the RID device 100 may serve as an ad hoc black box data recorder, storing data regarding the UAS 102”); Ex. 1009, 11 (“The RID product in its base form will include the following: . . . Persistent memory for configuration storage”), 15 (describing a “Black Box Data Recorder” that functions as “[i]ntegrated onboard storage of the host aircraft sUAS” and can be leveraged to “retrieve[]” “meaningful data...regarding the sUAS” in the case of incidents. A POSITA would have

⁴ I note that this interpretation is consistent with Patent Owner’s own interpretation of the claim, as indicated by both the complaint and Patent Owner’s briefing in the parallel district court case. *See* Ex. 1017, ¶82 (“It is also configured to ‘store the information in a storage,’ which is to say the identification information discussed for claim element 21.b, . . .”); Ex. 1018, 5 (“Claim 21 recites particular limitations for enabling a ground based system to automatically receive trusted information about a tracked UAV or set of UAVs by placing on each: . . . (b) a radio communication module coupled to the radio frequency communication antenna and configured for (i) transmission of identification information associated with the low-altitude aircraft through a transmitted radio signal that is stored aboard the UAV; . . .”).

understood that a “black box” was a well-known term of art that refers to an electronic recording device that stores data of an aircraft, which can be used to help identify an aircraft and retrieve sequence of events in recent flight history in the case of accidents to assess the cause of an accident. Black boxes, also known as Flight Data Recorders, have been used on aircraft since 1950s and 60s.

126. Second, to the extent “*the information*” is interpreted to refer to information associated with the “*received radio signal*” recited in limitation 21[c], *Beard* discloses that “the memory 106 of the RID device 100 may serve as an ad hoc black box data recorder, storing data regarding the UAS 102 ***as well as other nearby UAS, based on received identifier signals.***” Ex. 1008, 7:45-48 (emphasis added); *see also id.*, 7:48-51 (“If, for example, said nearby UAS are damaged or destroyed, the memory 106 may yet provide useful and retrievable data relevant to the damaged or destroyed UAS.”); Ex. 1009, 15 (disclosing that the black box data recorder stores data associated with both the “host aircraft sUAS, ***as well as data regarding nearby sUAS (leveraging the onboard receiver)***” (emphasis added)). A POSITA would have understood that “data regarding nearby sUAS” stored in the Black Box Data Recorder would include, for example, data identifying the nearby sUAS as received by the RID device. Accordingly, *Beard* discloses storing information it receives from other UASs via radio signals.

127. Thus, *Beard* teaches Limitation 21[c].

5. 21[d]: wherein the radio frequency communication antenna is coupled to the low-altitude aircraft and

128. *Beard* discloses, or at least renders obvious, Limitation 21[d] at least through its disclosure that the RID device, which includes antenna elements, is “attachable and connectable to a UAS.” As discussed above with reference to Limitation 21[a], *Beard* discloses, or at least renders obvious, that its RID device includes an antenna for communicating across various radio frequency bands. *Supra*, VIII.A.1.(b) *Beard* also explains that RID device is “attachable and connectable to a UAS 102.” Ex. 1008, 5:9-10; Ex. 1009, 5 (“the RID transmitter may be integrated tightly into the sUAS aircraft, or carried as a separate ‘stick on’ solution”), 11 (“The uAvionix base RID device is designed to be a ‘stick-on’ device with no required electrical or data integration to the sUAS.”). Accordingly, *Beard* discloses, or at least renders obvious, coupling an antenna (“*the radio frequency communication antenna*”) to its UAS (“*the low-altitude aircraft*”).

6. 21[e]: the radio communication module is configured to utilize a secure identifier,

129. *Beard* teaches Limitation 21[e] at least through its disclosure of using a digital signature to secure transmissions of UAS identification information made by the RF transceiver (“*the radio communication module*,” *see supra*, XI.A.3) of the RID device. As discussed above with reference to Limitation 21[b], *Beard* discloses that its RF transceiver transmits position data and identification information (an

“*identifier*”) in “direct-broadcast identifier signals.” *See supra*, XI.A.3. *Beard* further discloses that the identifier signals include “digital signatures encoded into the identifier signals,” which, when received by a receiving device, are validated to verify the identity of the source of the identifier signal (*i.e.*, the transmitting UAS). Ex. 1008, 3:30-36 (“The receiver device includes . . . cryptographic keys for verifying digital signatures encoded into the identifier signals (e.g., verifying the identity of a transmitting UAS).”), 8:39-42 (“The receiver device 120a may additionally store to memory (132) private keys associated with the UAs 102b in order to validate a digital signature transmitted via the identifier signal sent by the RID device 100a.”), 9:8-12 (“Accordingly, a receiver device 120b in standalone mode may decode a digital signature transmitted with the identifier signal, and verify the digital signature (and thus the identity of the UAS 102f-g) if the appropriate private keys are stored to memory.”); Ex. 1009, 7-8 (describing that a receiving device makes available the data received in an RID transmission, “including at a minimum the FAA registration ID, digital signature, and position information of the sUAS”), 11 (describing use of “anti-spoofing digital signature”).

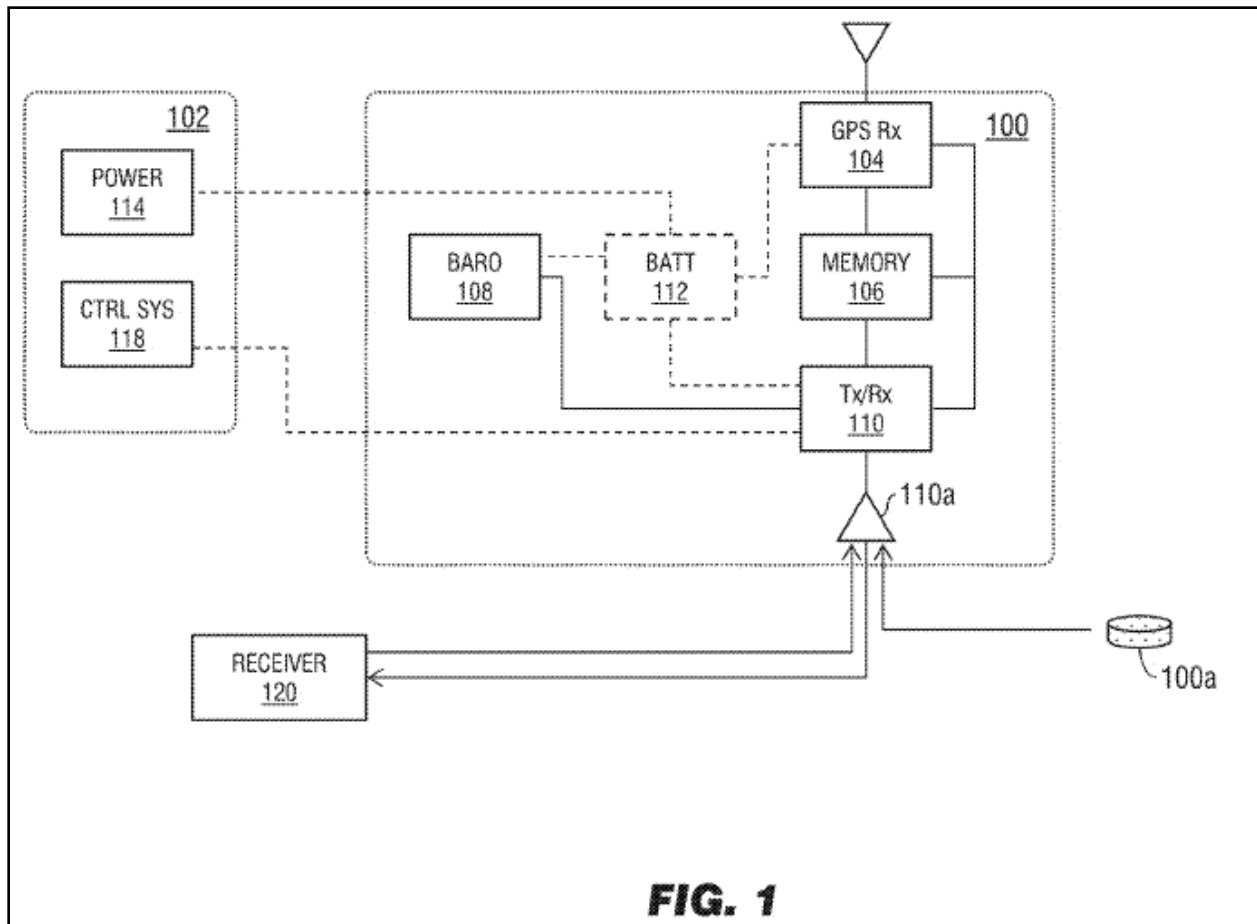
130. A POSITA would have understood that the encoded identifier signals, and the identification information included therein, is “*secure*” because a receiving device needs a “private” or “cryptographic” key to decode the signature, thereby securing access to the information from parties that do not hold the appropriate key.

See Ex. 1008, 3:30-36 (“The receiver device includes . . . *cryptographic keys for verifying digital signatures* encoded into the identifier signals (e.g., verifying the identity of a transmitting UAS).”) (emphasis added), 8:39-42 (“The receiver device 120a may additionally store to memory (132) *private keys associated with the UAS 102b in order to validate a digital signature* transmitted via the identifier signal sent by the RID device 100a.”) (emphasis added); Ex. 1009, 7-8 (describing that “[b]asic validation” of the digital signature is achieved “if the transmissions came from the correct private key and the information was not spoofed,” and that a receiving device can determine if a “private key has been compromised or if the key was not on the CRL [certification revocation list].”). Accordingly, *Beard* teaches that RF transceiver (“*the radio communication module*”) is configured to broadcast (“*is configured to utilize*”) the identification information as secured by the digital signature (“*a secure identifier*”).

7. 21[f]: and the radio communication module is configured for two-way communication with a remote portable detection system;

131. *Beard* teaches Limitation 21[f] at least through its disclosure of RF transceiver (“*the radio communication module*”) communicating with a “receiver” (“*a remote portable detection system*”). *Beard* discloses that its RF transceiver transmits identifier signals to “any receivers (120) equipped to receive and decode transmitted identifier signals.” Ex. 1008, 5:41-57; Ex. 1009, 5-6 (describing operation of a “portable receiver” that “allow[s] security personnel to receive the

RID signal”). *Beard* also discloses that such receivers can also “command a directly integrated RID device 100c (e.g., aboard the UAS 102f) to perform various functions,” by “remotely transmit[ting] commands to the control system (118, FIG. 1) of the UAS 102f.” Ex. 1008, 10:12-20; Ex. 1009, 5 (describing that the “portable receiver would allow security personnel to receive the RID signal”), 15 (explaining that the “RID device is both a transmitter and receiver,” which “enables authorized security personnel to send a signal to the RID to command the autopilot to perform any number of functions”). As shown in Figure 1 of *Beard*, such communications between a receiver 120 and a UAS control system 118 pass through antenna elements 110a and RF transceiver 110 of the target RID device:



Ex. 1008, Fig. 1.

132. Thus, *Beard*'s disclosure of its RF transceiver both transmitting identifier signals to and receiving command signals from a receiver teaches "*the radio communication module is configured for two-way communication with*" the receiver.

133. Further, *Beard*'s receiver is "a remote portable detection system." *Beard* explains that a receiver can be, for example, a "portable communications or computing device (e.g., a smartphone or tablet) carried by authorized personnel." Ex. 1008, 7:11-17; Ex. 1009, 3 (describing receivers as "portable in nature"), 4

(describing “Ground based RID receivers” as, for example “pocket-sized mobile receivers for roaming security personnel”). And the function of the receiver is to receive identifier signals transmitted by RID devices and display the information contained therein, including the identification data of the associated UAS and the UAS’s position data. Ex. 1008, 9:67-10:12; Ex. 1009, 4-6. Accordingly, *Beard*’s receiver operates as a system for detecting and identifying UASs within its range.

134. Thus, *Beard* teaches Limitation 21[f].

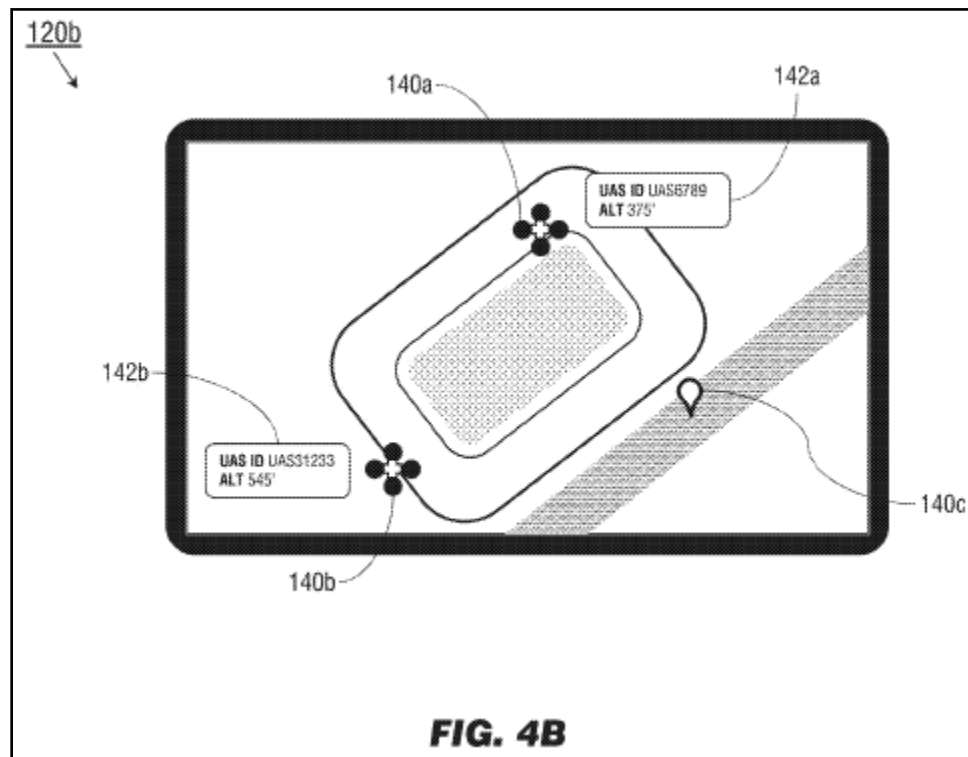
8. 21[g]: and wherein the device is coupled to the low-altitude aircraft and

135. As discussed above with reference to Limitation 21[d], *Beard* discloses that its RID device (“*the device*”) is “attachable and connectible to a UAS 102” (“*is coupled to the low-altitude aircraft*”). *Supra*, VIII.A.1.(e) (citing Ex. 1008, 5:9-10; Ex. 1009, 5, 11). For at least the same reasons, *Beard* discloses Limitation 21[g].

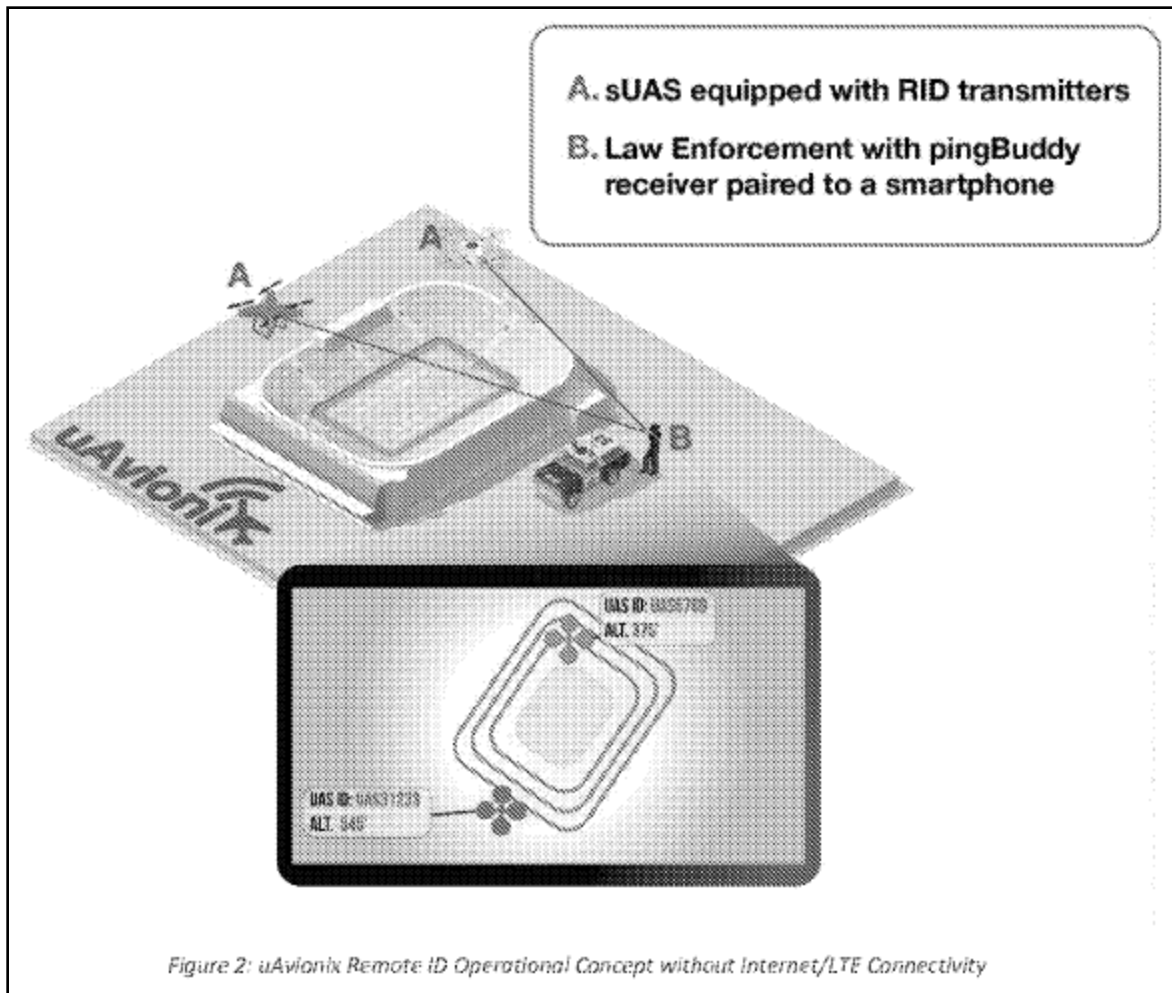
9. 21[h]: the remote portable detection system includes a user interface configured to provide to a user, information associated with a plurality of different low-altitude aircrafts detected by the remote portable detection system.

136. *Beard* teaches Limitation 21[h] at least through its disclosure of the receivers displaying identification data of detected UASs on the screens of associated mobile devices. For example, *Beard* discloses that “receiver device 120a may include onboard processors (130) and memory (132) as well as a display surface (134) for displaying identifier and position data decoded from identifier signals

transmitted by RID device (100a) aboard a proximate UAS 102b.” Ex. 1008, 8:28-32; Ex. 1009, 4 (“Mobile app or apps which can operate in an internet denied or internet available environments to provide sUAS position and operator identifying information to viewer”), 5 (“This basic data will allow visual correlation of the aircraft with the position on a map,...”), 6 (“The RID Display Application is used to observe and identify sUAS while in flight.”), 7 (describing process of transferring received sUAS data from the mobile receiver to a mobile application for display). Figure 4B of *Beard* and Figure 2 of *Beard Provisional*, copied below, depict such display of received UAS data:



Ex. 1008, Fig. 4B.



Ex. 1009, Fig. 2. As shown, the mobile displays depict the device ID (e.g., “UAS ID”) and altitude (e.g., “ALT”) of multiple detected UASs.

137. Accordingly, *Beard* discloses that its receivers and associated mobile devices (“*the remote portable detection system*”) display to a user (“*provide to a user*”) at least the device identification and position data of UASs whose identifier signals are received by the receivers (“*information associated with a plurality of different low-altitude aircrafts detected by the remote portable detection system*”).

XII. GROUND 2: OBVIOUS OVER TAVEIRA, WANG, AND GONG**A. MOTIVATION TO COMBINE****1. Taveira and Wang**

138. *Taveira* discloses a system for controlling drone operation wherein a drone is configured for “bi-directional” wireless communication such that the drone may transmit information to, and receive information from, other devices. *Id.*, [0057]. For example, *Taveira* teaches that the drone may transmit “drone information,” such as “a drone identifier, a drone access level, drone payment information, drone authorization credentials, and/or other information” to a wireless communication device. Ex. 1010, [0110], [0117]. And the drone may receive a radio frequency (RF) signal from an “RF emitter,” where the received signal includes a “unique identifier” such as a “service sector identification (SSID), a media access control (MAC) address, radio station call sign, [or] cell ID.” Ex. 1010, [0056]. *Wang* discloses that wireless communications between a base station 300 and a UAV 201 are encrypted, and that “suitable encryption methods” include “SSID hiding” and “MAC ID filtering,” for example. Ex. 1011, [0160], Fig. 1. *Wang* explains that such encryption “may be advantageous for secure flight task applications.” *Id.*, [0160].

139. A POSITA would have been motivated to combine *Taveira* and *Wang* such that the wireless communications involving *Taveira*’s drone are encrypted as

taught by *Wang* (e.g., using “SSID hiding” and “MAC ID filtering”). A POSITA would have been motivated to combine these references for several reasons.

140. First, both *Taveira* and *Wang* references are directed to drone technologies and wireless communication involving drones. Ex. 1010, [0057] (“The processor 120 may use the radio module 130 to conduct wireless communications with a variety of wireless communication wireless communication devices 170 such as beacon, a server, smartphone, tablet, or other device with which the drone 100 may be in communication.”); Ex. 1011, [0160] (“The UAVs 201 of the mobile platform management system 100 can be equipped to communicate wirelessly with the base station 300. A selected UAV 201 associated with the mobile platform management system 100 can be likened to a communications endpoint, e.g., a cell phone, within a wireless communications network. Thus, any conventional wireless communication protocol appropriate for communications endpoints can be suitable for use to facilitate communications between the UAVs 201, the base station 300, and any other components of the mobile platform management system 100.”). Accordingly, a POSITA seeking to implement the system taught by *Taveira* would look to other references that describe techniques for facilitating wireless communications with a drone, such as *Wang*.

141. Moreover, *Taveira* itself provides a motivation to combine with *Wang*’s encryption techniques, explaining that because drones are “conspicuous,” they may

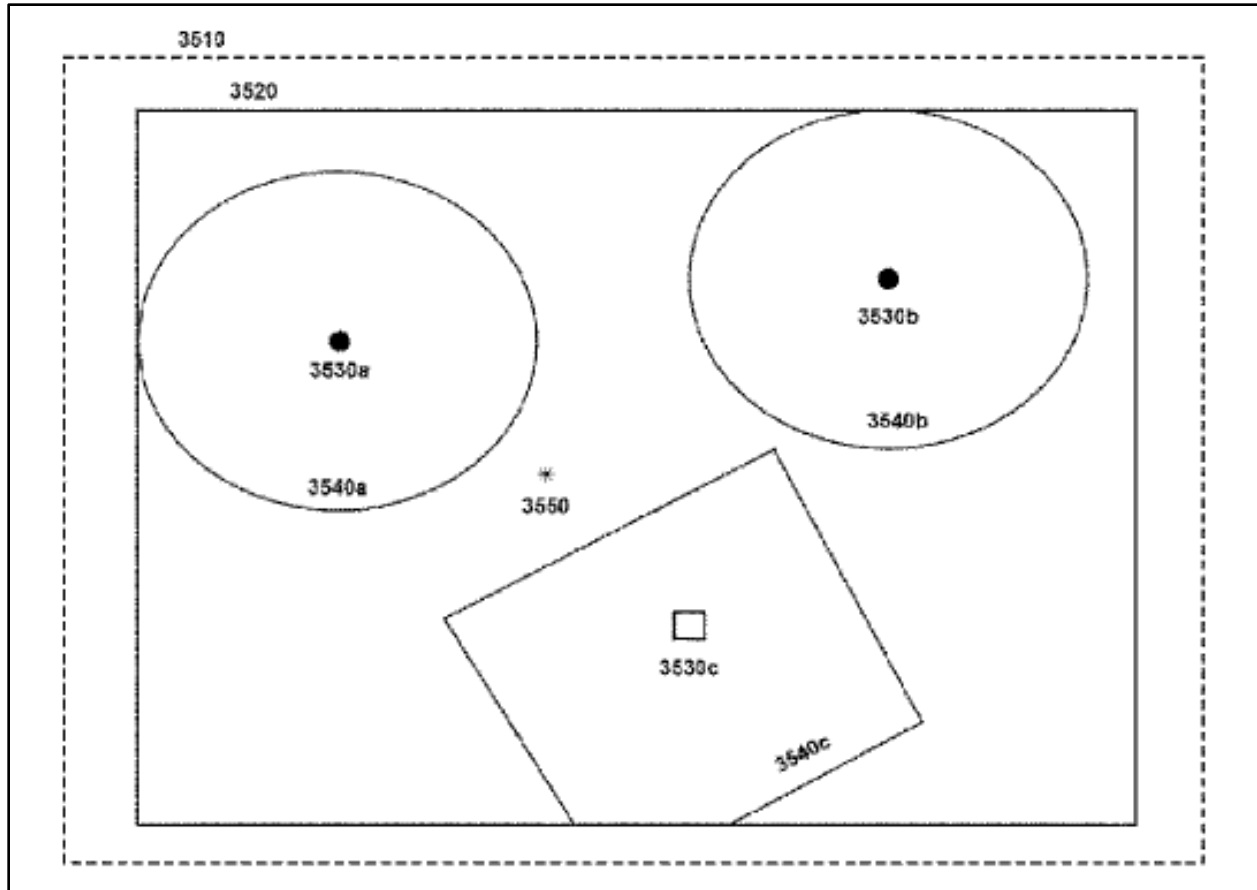
be “vulnerable to tampering,” intercepting, interfering, or hijacking during flight. Ex. 1010, [0002]. Further, *Taveira* suggests that “identifying information may also be encoded to prevent or discourage tampering or spoofing.” *See* Ex. 1010, [0091]. Thus, a POSITA would have sought out various solutions to prevent the described tampering and interfering, and an obvious and known solution would be to encrypt any signals involved in wireless communications with a drone as taught by *Wang* to prevent unauthorized access to and use of the information contained in such signals.

142. Further, combining *Wang*’s teachings regarding encrypting wireless communications between a UAV and another device with *Taveira*’s drones that are configured for wireless communications is merely combining prior art elements (i.e., encrypting wireless communications between a UAV and another device using techniques such as SSID hiding and MAC ID filtering, as taught by *Wang*) to known methods (i.e., *Taveira*’s wireless communications system between a drone and another device) to yield predictable results (i.e., producing a wireless communication system that utilizes encrypted communications). Indeed, encrypting SSIDs and MAC addresses according to various encryption methods was a commonly-used technique to improve system security. *See, e.g.*, Ex. 1018 (describing encrypting SSIDs using hash functions), Ex. 1019 (describing the use of MAC address filtering). Accordingly, a POSITA would have been motivated to combine *Wang*’s teachings of encrypting wireless communications with *Taveira*’s

wireless communication system and would have reasonably expected success in doing so.

2. Taveira and Gong

143. *Taveira* discloses that its drone may perform bi-directional wireless communication with a “wireless communication device,” which may be a “smartphone” or a tablet” that is controlled by a “drone operator, a third party service (e.g., package delivery, billing, etc.), or an operator of a restricted area.” Ex. 1010, [0057]. *Gong* describes a “remote device” that may be a “remote controller” that wirelessly communicates with a UAV and shows on a display “a location of [] [a] first UAV” and “may...show a location of [] [a] second UAV.” Ex. 1012, [0182], [0955]. Figure 35 of *Gong*, copied below, shows an example of such user interface that displays the location of a UAV 3550:



Ex. 1012, Fig. 35.

144. A POSITA would have been motivated to incorporate the functionality of *Gong*'s "remote device," which is configured to display information associated with detected UAVs, into *Taveira*'s wireless communication device for several reasons. First, both *Taveira* and *Gong* are directed to drone technologies and wireless communication involving drones, and a POSITA would have recognized that these references are related to the same field of art and could be combined to gain functionalities and benefits discussed by either reference. Ex. 1010, [0054]; Ex. 1012, [0233].

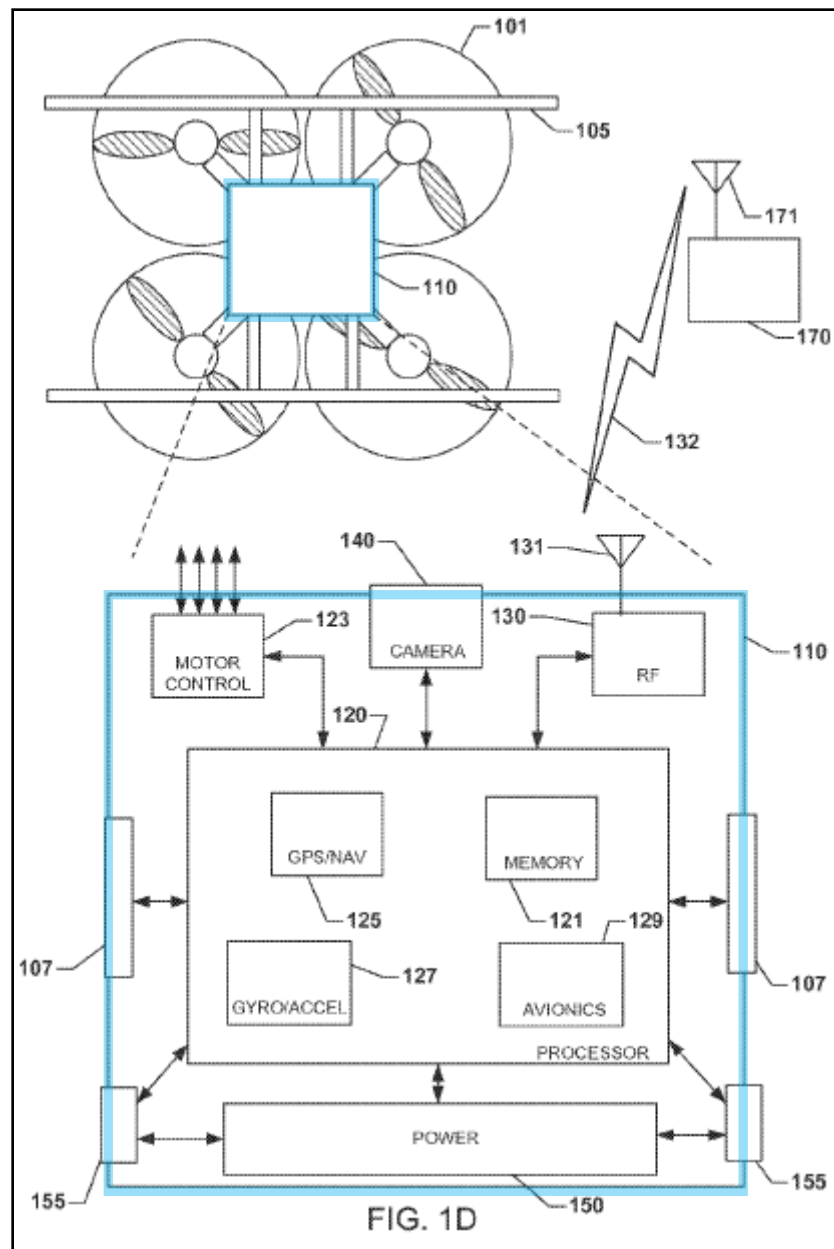
145. Second, it would have been common sense to a POSITA that *Taveira*'s wireless communication device would display detected drone information as taught by *Gong* to further *Taveira*'s goal of controlling drone access to restricted spaces. *Taveira* explains that its system is configured for "providing conditional access for a drone for accessing a restricted area," and that the operator of a wireless communication device may be, for example, an "operator of a restricted area." Ex. 1010, Abstract, [0057]. It would have been common sense to a POSITA that an operator of a restricted space would want to know the identity and location of drones approaching the restricted space and would have incorporated the functionality of *Gong*'s remote controllers (i.e., displaying information of detected drones) to improve their ability to monitor the restricted space and respond to unauthorized drones in the space. Indeed, *Gong* explains that "tracking UAV usage" improves safety, as corrective action can be taken when unauthorized drones are detected in a particular area. Ex. 1012, [0004]. This common-sense implementation of *Gong* is also apparent in view of *Taveira*'s teaching that the wireless communication devices can be smartphones or tablets, which are known devices that comprise displays for displaying information to users. Ex. 1010, [0057].

146. Third, combining *Taveira*'s teaching regarding receiving drone information at a wireless communication device with *Gong*'s disclosures of a remote controller for displaying information of multiple detected drones involves

merely combining prior art elements (i.e., *Gong*'s remote controllers and associated displays) to known methods (i.e., *Taveira*'s UAV identification system that involves transmitting UAV information to wireless communication devices) to yield predictable results (i.e., a drone identification system that includes remote devices that can display information associated with detected drones). *Taveira* describes scenarios where "two or more of the drones...may approach the restricted area 312 at the same time," so such a combination would have allowed a wireless communication device operator to be aware of multiple drones operating in a particular airspace, improving the operator's monitoring of a particular space. Ex. 1010, [0078]. And implementing *Gong*'s remote controller devices would have been routine and well known, and would have been easily effectuated by a POSITA, as *Gong* describes deploying these devices in an environment similar to that of *Taveira* (i.e., a wireless communication environment between drones/UAVs and external mobile devices). Accordingly, a POSITA would have been motivated to combine *Wang*'s teachings of encrypting unique identifiers with *Taveira*'s wireless communication system and would have reasonably expected success in doing so.

B. CLAIM 21**1. 21[p]: A device configured to communicate identification information associated with a low-altitude aircraft, the device comprising:**

147. To the extent the preamble is limiting, *Taveira* teaches the preamble at least through its disclosure of control unit 110. *Taveira* describes “drone 100” that has a “control unit 110” that includes “a processor 120, a radio module 130, and a power module 150.” Ex. 1010, [0054]. Control unit 110 is depicted in Figure 1D of *Taveira*, annotated below:



Ex. 1010, Fig. 1D (annotated).

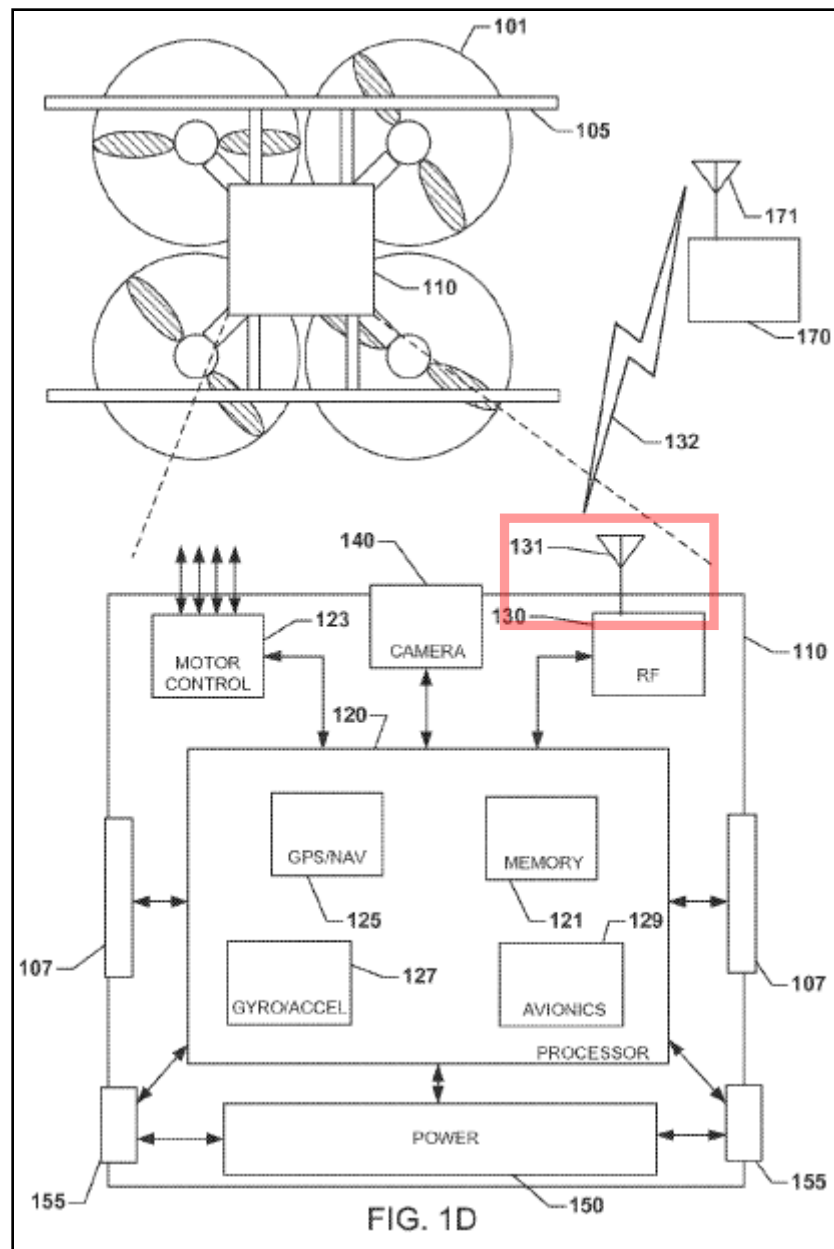
148. *Taveira* explains that “the processor of the drone 100 may provide drone information,” such as “a drone identifier, a drone access level, drone payment information, drone authorization credentials, and/or other information” to “an access server 240” (Ex. 1010, [0110]) or a “beacon device” (*id.*, [0117]). *Taveira* explains

that the drone identifier can be a “unique identifier (ID)” that “may allow the drone to be identified by network components, such as servers..., beacons..., other drones, and so on.” *Id.*, [0168]. Accordingly, *Taveira*’s control unit 110 discloses a “*device configured to communicate identification information associated with*” drone 100.

149. Further, *Taveira* explains that “drones may often fly at low altitude (e.g., below 400 feet).” Ex. 1010, [0044]. Accordingly, a POSITA would have understood that drone 100 is a “*low-altitude aircraft*,” and that *Taveira*’s “drone identifier” is “*identification information associated with a low-altitude aircraft*.” This understanding of *Taveira*’s drone as a “*low-altitude aircraft*” is consistent with the ’959 Patent, which acknowledges that a “drone” is an example of a “low altitude aircraft.” See Ex. 1001, 12:61-62.

2. 21[a]: a radio frequency communication antenna;

150. *Taveira* teaches Limitation 21[a] at least through its disclosure of transmit/receive antenna 131. *Taveira* describes “radio module 130” comprises “transmit/receive antenna 131.” Ex. 1010, [0057]. As shown in Figure 1D of *Taveira*, annotated below, transmit/receive antenna 131 is coupled to radio module 130:



Ex. 1010, Fig. 1D (annotated).

151. *Taveira* explains that radio module 130 utilizes a “bi-directional wireless communication link” to communicate with “wireless communication devices 170” using transmit/receive antenna 131. Ex. 1010, [0057]. For example, radio module 130 facilitates the reception of “navigation signals” that are “received

from recognizable RF emitters (e.g., AM/FM radio stations, WiFi access points, and cellular network base stations) on the ground.” Ex. 1010, [0056]; *see also id.*, [0057] (describing radio module 130’s interaction with devices that use “different radio access technologies”). Given radio module 130’s use of various radio frequency (RF) signals to communicate, and POSITA would have understood that transmit/receive antenna 131 is a “*radio frequency communication antenna.*”

3. 21[b]: a radio communication module coupled to the radio frequency communication antenna and configured to transmit identification information associated with the low-altitude aircraft through a transmitted radio signal.

152. *Taveira* teaches Limitation 21[b] at least through its disclosure of radio module 130. As discussed above with reference to Limitation 21[a], *Taveira* describes that radio module 130 is coupled to transmit/receive antenna 131 and that radio module 130 communicates via radio frequency (RF) signals using transmit/receive antenna 131. *See supra*, XII.B.2. For at least the same reasons, *Taveira*’s radio module 130 discloses “*a radio communication module coupled to the radio frequency communication antenna and configured to transmit . . . through a transmitted radio signal.*”

153. And as discussed above with reference to Limitation 21[p], *Taveira* describes that control unit 110 includes a processor that “may provide drone information” such as “a drone identifier” (“*identification information associated*

with the low-altitude aircraft”) to “an access server 240” or a “beacon device.” *See supra*, XII.B.1; Ex. 1010, [0054], [0110], [0117]. Moreover, *Taveira* explains that drone 100 can transmit “identification, which may include an assigned drone access level.” Ex. 1010, [0036]. The processor, which corresponds to processor 120 in Figure 1D, uses radio module 130 that, as discussed above with reference to Limitation 21[a], “conducts wireless communication” using “[a] bi-directional wireless communication link 132” that is “established between transmit/receive antenna 131 of the radio module 130 and transmit/receive antenna 171 of the wireless communication device 170,” where radio frequency (RF) signals are transmitted and received. *See supra*, XII.B.2; Ex. 1010, [0057]. Radio module 130 (“*a radio communication module*”) therefore transmits the drone identifier (“*identification information associated with the low-altitude aircraft*”) using radio frequency (RF) signals via communication link 132.

4. 21[c]: wherein the radio communication module is configured to receive a received radio signal and store the information in a storage,

154. *Taveira* teaches Limitation 21[c] at least through its disclosure of receiving navigation signals from external RF emitters and storing associated data as well as storing its own identification data. *Taveira* describes that radio module 130 (“*the radio communication module*”) “may be configured to receive navigation signals, such as beacon signals from restricted areas, signals from aviation

navigation facilities, etc., and provide such signals to the processor 120 and/or the navigation unit 125 to assist in drone navigation,” where such signals include those from “recognizable RF emitters (e.g., AM/FM radio stations, WiFi access points, and cellular network base stations) on the ground.” Ex. 1010, [0056]. Accordingly, *Taveira* teaches a “radio communication module [that] is configured to receive a received radio signal.”

155. To the extent “*the information*” is interpreted to refer to information associated with the “*received radio signal*” recited in limitation 21[c], *Taveira* discloses that “the locations, unique identifiers, signal [sic] strengths, frequencies, and other characteristic information of such RF emitters may be stored in a database and used to determine position (e.g., via triangulation and/or trilateration) when RF signals are received by the radio module 130,” where “such a database of RF emitters may be stored in the memory unit 121 of the drone 100.” Ex. 1010, [0056]. Because the stored “locations, unique identifiers, single strengths, frequencies, and other characteristic information of such RF emitters” may be used to determine position when “RF signals are received,” a POSITA would have understood or at least found obvious that such RF signals are also stored in the memory unit 121 of drone 100 so that the received RF signals can be used with the stored “locations, unique identifiers, single strengths, frequencies, and other characteristic information of such RF emitters” to determine emitter position.

156. Additionally, *Taveira* describes that drone 100 may have a “database 341 [that] may be stored in memory” of the drone, which may receive “updated database information [] from a server (e.g., 240).” Ex. 1010, [0088]. As discussed above with reference to Limitation 21[p], access server 240 is one of the devices with which drone 100 may communicate. *See supra*, XII.B.1; Ex. 1010, [0110]. Accordingly, a POSITA would have understood or at least found obvious that such database information would have been received by radio module 130 via radio signals because this component is what receives information that is broadcasted and received by drone 100. Moreover, because such database information would have been received by radio module 130 and sent by radio module 130 to the processor for storage in the memory of drone 100 (*see* Ex. 1010, Fig. 1 (showing processor 120 comprising memory 121)), a POSITA would have understood that radio module 130 stores the received database information in the memory (“*wherein the radio communication module is configured to... store the information in a storage*”). *Id.*

157. To the extent “*the information*” is interpreted to refer to the “*identification information associated with the low-altitude aircraft*” recited in Limitation 21[b],⁵ *Taveira* discloses storing identification data associated with drone 100. *Taveira* explains that drone 100 can transmit “identification, which may

⁵ As noted above in Footnote 4, this interpretation is consistent with Patent Owner’s interpretation of the claim as indicated in the parallel district court case.

include an assigned drone access level,” making the drone access level “*identification information associated*” with drone 100 as discussed above with reference to Limitation [21b]. *See supra*, XII.B.3; Ex. 1010, [0036]. *Taveria* teaches that this access level information of a drone may be stored in “database 341,” and that “database 341 may be stored in memory of a drone.” Ex. 1010, 0079 (“database 341 may store various information regarding access levels 343”), [0088], Figs. 3C-3E (showing database 341 that includes “access level[s]”). As noted above, database 341 may be updated with database information received by radio module 130, such that a POSITA would have understood that radio module 130 would have sent any received access level information to the processor for storage in memory of drone 100. Ex. 1010, [0088].

5. 21[d]: wherein the radio frequency communication antenna is coupled to the low-altitude aircraft and

158. *Taveira* teaches Limitation 21[d] at least through its disclosure of transmit/receive antenna 131 being coupled to drone 100. As discussed above with reference to Limitation 21[a], *Taveira* describes that “transmit/receive antenna 131” is part of control unit 110, and that control unit 110 is attached to drone 100. *See supra*, XII.B.2; Ex. 1010, [0057], Fig. 1D. Thus, transmit/receive antenna 131 (“*the radio frequency communication antenna*”) is coupled to drone 100 (“*the low-altitude aircraft*”).

6. 21[e]: the radio communication module is configured to utilize a secure identifier,

159. The *Taviera-Wang* combination renders obvious Limitation 21[e] through its description of using SSIDs that are encrypted upon transmission. *Taveira* describes that radio module 130 receives an RF signal from an RF emitter, where the signal includes a “unique identifier” such as a “service sector identification (SSID), a media access control (MAC) address, radio station call sign, [or] cell ID,” and radio module 130 provides this signal to processor 120, which “use[s] that information to obtain the ground coordinates and signal strength of the detected RF emitter” from a database of RF emitter characteristics and in turn “estimate the location of the drone 100 relative to the coordinates.” Ex. 1010, [0056]. Therefore, radio module 130 (“*the radio communication module*”) is “*configured to utilize an identifier*” of an RF emitter, such as an SSID, by providing it to processor 120 so that the processor can estimate the drone’s location.

160. Further, in the combination of *Taveira* and *Wang*, the identifier of the RF emitter is a “*secure identifier*.” Specifically, *Wang* teaches that wireless communications between a base station 300 and a UAV 201 are encrypted, and that “suitable encryption methods” include “SSID hiding” and “MAC ID filtering.” Ex. 1011, [0160], Fig. 1. Thus, in the combination of *Taveira* and *Wang*, *Taveira*’s received “unique identifier,” which is an SSID or MAC address, and that is utilized by radio module 130 as discussed, is a “*secure identifier*” because it would have

been encrypted using SSID hiding or MAC ID filtering as taught by *Wang*. See *supra*, XII.A.1. A POSITA would have known that un-encrypted signals, such as certain GNSS signals, have been known to be subject to spoofing, which creates a security risk for UAS. In this case, a malignant agent could pose to a GPS transmitter and attack the UAS navigation system. One way to solve this problem that would have been known to the POSITA would be to encrypt such signals. As such, a POSITA would have been motivated to ensure that information sensitive to security, such as information identifying a UAS would be encrypted before transmission, even when the information is transmitted broadly to all users.

161. In addition, the *Taviera-Wang* combination renders obvious Limitation 21[e] through its description of transmitting drone information via encrypted signals. As discussed above with reference to Limitation 21[b], *Taveira*'s radio module 130 transmits drone information, such as a drone identifier, and other identification using RF signals. See *supra*, VIII.B.2.(c). *Taveira*'s drone information (e.g., a drone identifier) therefore discloses an “*identifier*” because it identifies the associated drone. And in the combination of *Taveira* and *Wang*, transmitted drone information is a “*secure identifier*” because, as just discussed, *Wang* teaches that wireless communications between a base station 300 and a UAV 201 are encrypted according to known encryption techniques. Ex. 1011, [0160], Fig. 1. Thus, in the combination of *Taveira* and *Wang*, *Taveira*'s transmitted drone information is a “*secure*

identifier” because it would have been encrypted as taught by *Wang*. *See supra*, XII.A.1. Accordingly, the *Taveira-Wang* combination teaches that the radio module 130 (“*the radio communication module*”) is configured to transmit (“*is configured to utilize*”) encrypted drone information (“*a secure identifier*”).

162. In the alternative, *Taveira* discloses that its drone 100 “may receive one or more respective heart beat signals...from components of the conditional access system, such as the server 240, the navigation unit 125, and/or the database 341/data storage device 340,” which “confirm that these systems are functioning properly to enable the drone 100 to confirm that the guidance and information systems have not been compromised.” Ex. 1010, [0091]. The heart beat signals may be “provided with identifying information of the respective sending system, such as a device identifier other identifier,” which “may also be encoded to prevent or discourage tampering or spoofing.” *Id.* Upon determining that heart beat signal has been received from the relevant, a processor of the drone (e.g., processor 120) “may proceed with flight operations.” *Id.*, [0092]. A POSITA would have understood that *Taveira*’s radio module 130, which is responsible for receiving wireless communication signals (*see supra*, VIII.B.2.(d)), would have received the heart beat signals from the conditional access system. Accordingly, *Taveira* discloses that radio module 130 (“*the radio communication module*”) is “*configured to utilize a secure identifier*” of a received heart beat signal (*i.e.*, an encrypted identifier

included in the heart beat signal) by providing it to processor 120 so that the processor can determine that the associated system is still operational.

7. 21[f]: and the radio communication module is configured for two-way communication with a remote portable detection system;

163. *Taveira* teaches Limitation 21[f] at least through its disclosure of bi-directional communication between radio module 130 and wireless communication device 170. In the alternative, the *Taveira-Gong* combination renders obvious Limitation 21[f] in view of *Gong*'s disclosure of bi-directional communication with a remote device.

164. *Taveira* describes that control unit 110 includes a processor that “may provide drone information” such as “a drone identifier” to “an access server 240.” Ex. 1010, [0110]. The processor, which is processor 120 in Figure 1D, includes radio module 130 that “conduct[s] wireless communication” using “[a] bi-directional wireless communication link 132” that is “established between transmit/receive antenna 131 of the radio module 130 and transmit/receive antenna 171 of the wireless communication device 170,” where radio frequency (RF) signals are transmitted and received, and wireless communication device 170 is, for example, a “smartphone” or a “tablet.” *Id.*, [0057]; *see also supra*, XII.B.2 (describing use of RF resources for wireless communication). Accordingly, *Taveira* discloses that the radio module 130 (“the radio communication module”) is

configured for bi-directional communication (“two-way communication”) with a wireless communication device 170 (“*a . . . system*”).

165. A POSITA would have understood that wireless communication device 170 is a remote portable detection system. As noted above, communication device 170 can be a “smartphone” or “tablet,” which are well known portable devices, and wireless communication device 170 is located on the ground (“remote” from drone 100) and communicates with drone 100 via wireless signals. Ex. 1010, [0045] (explaining a drone may be “remotely controlled”), [0057]. Moreover, wireless communication device 170 “detects” a drone 100 because it has established a bi-directional wireless communication link 132, which a POSITA would have understood or at least found obvious to require detecting parameters associated with communication with drone 100. *Id.*, [0057], [0069] (describing establishment of a communication link between a drone and a wireless communication device upon the drone’s approach).

166. To the extent *Taveira*’s device 170 is not found to be a “remote portable detection system,” the combination of *Taveira* and *Gong* teaches this. *Gong* describes a “remote device” that may be a “remote controller” that communicates with a UAV using “wireless communications” such as “WiFi” and that shows on a display “a location of [] [a] first UAV” and “may...show a location of [] [a] second UAV.” Ex. 1012, [0182], [0955]. The “location of a UAV shown on the remote

device may be updated in real-time.” Id., [0957]. Moreover, *Gong* describes that its remote controller can be implemented as a “geo-fencing device” that “detect[s] the presence of the UAV” and that the geo-fencing device can be “portable.” Id., [0593], [0600], [0628]; see also id., [0137] (describing the remote controller “may be a...mobile device” such as a “smartphone, cellular phone, [or] tablet.”). The geo-fence device further interacts with multiple UAVs, providing a “reference point for different sets of flight regulations for different UAVs in different circumstances that may approach the geo-fencing device.” Id., [0864]-[0869]. Thus, in the combination of *Taveira* and *Gong*, *Taveira*’s wireless communication device 170, which can be a smartphone or tablet, is enhanced by remotely detecting the presence of one or more drones 100 as taught by *Gong*, thereby teaching a “remote portable detection system.”

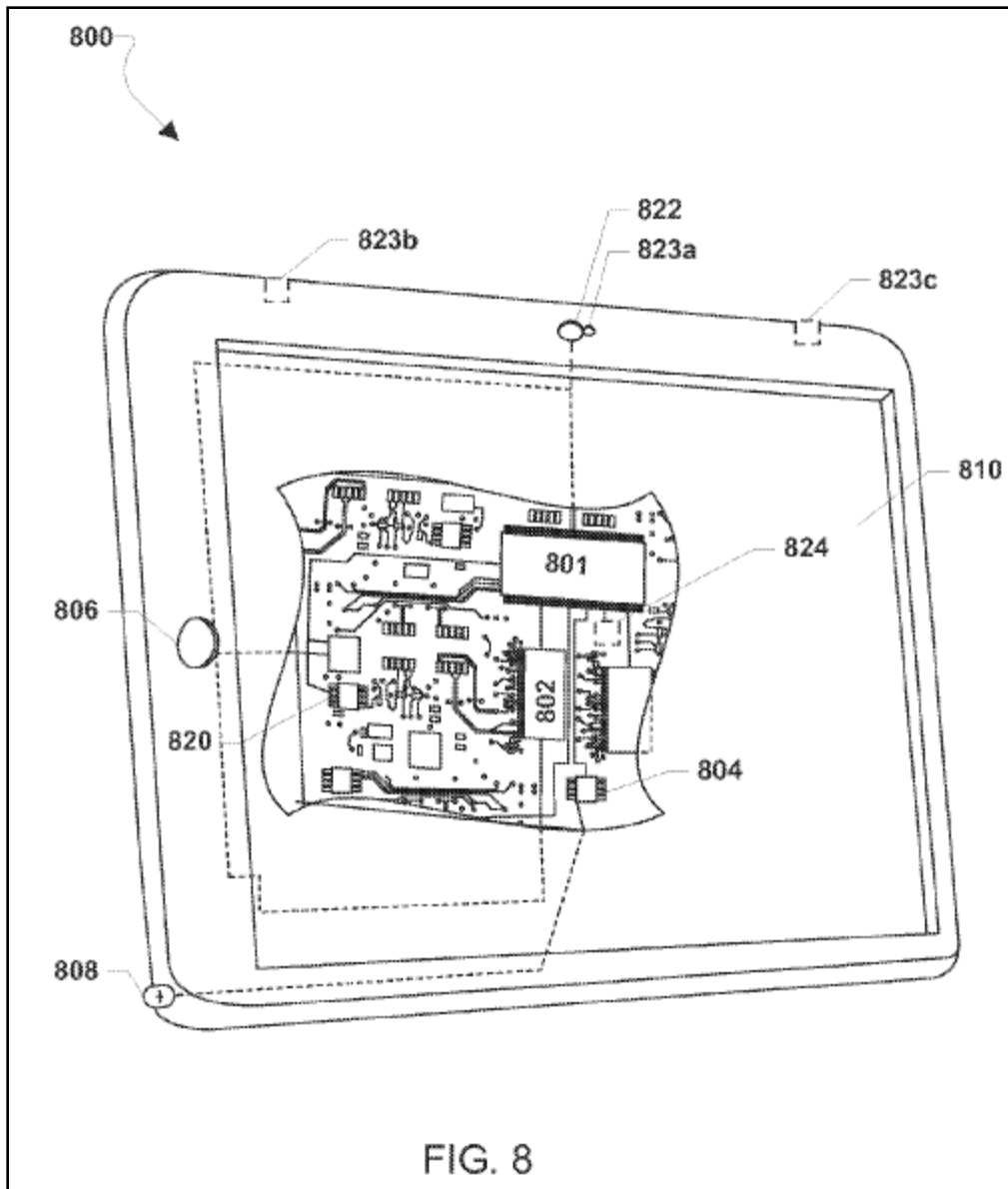
8. 21[g]: and wherein the device is coupled to the low-altitude aircraft and

167. *Taveira* teaches Limitation 21[g]. *Taveira* describes control unit 110 (“*the device*”) is coupled to drone 100 (“*the low-altitude aircraft*”). See *supra*, XII.B.1.

9. 21[h]: the remote portable detection system includes a user interface configured to provide to a user, information associated with a plurality of different low-altitude aircrafts detected by the remote portable detection system.

168. *Taveira* teaches Limitation 21[h] at least through its disclosure regarding wireless communication device 170. In the alternative, the *Taveira-Gong* combination teaches Limitation 21[h] in view of *Gong*'s disclosure regarding detecting multiple drones.

169. *Taveira* describes that wireless communication device 170 can be a smartphone or tablet. Ex. 1010, [0057]. A POSITA would have understood that wireless communication device 170 therefore includes a user interface because smartphones and tablets are known to include a user interface; indeed, *Taveira* itself describes “[t]he various embodiments may be implemented in any of a variety of tablet mobile computing devices, an example of which (800) is illustrated in FIG.8,” where tablet 800 includes a “touch screen display 810.” Ex. 1010, [0187]; id., [0181]-[0182] (describing a mobile computing device 700 having a display).



170. Ex. 1010, Fig. 8.

171. To the extent *Taveira* does not explicitly teach that the user interface of the wireless communication device is “configured to provide to a user, information associated with a plurality of different low-altitude aircrafts detected by the remote portable detection system,” the combination of *Taveira* and *Gong* does. As discussed for Limitation 21[e], a POSITA would have enhanced *Taveira*’s wireless

communication device 170 according to *Gong*'s teachings, such that wireless communication device 170 would remotely detect the presence of one or more drones 100 and display such detected drones via a user interface. *See supra*, XII.B.6. Accordingly, the *Taveira-Gong* combination renders obvious Limitation 21[h].

XIII. GROUND 3: OBVIOUS OVER *TAVEIRA*, *QI*, AND *GONG*

1. *Taveira* with *Qi*

172. *Taveira* discloses a radio module 130 that receives a radio frequency (RF) signal from an RF emitter and that the received signal includes a “unique identifier” such as a “service sector identification (SSID), a media access control (MAC) address, radio station call sign, [or] cell ID.” Ex. 1010, [0056]. *Qi* discloses that utilizing SSIDs for wireless communication may periodically “update the SSID based on [an] update of the service name key,” and that such “updating the SSID, e.g., along time, may increase the security of the SSID and/or may reduce the probability of an attacker to discover the service name of the service based on the SSID, e.g., compared to an implementation in which the SSID is kept constant.” Ex. 1013, [0168]-[0170].

173. A POSITA would have been motivated to combine *Taveira* and *Qi* such that the “unique identifiers” included in *Taveira*'s wireless communications (e.g., the SSID and MAC address) are periodically updated as taught by *Qi*. A POSITA would have been motivated to combine these references for several reasons.

174. First, *Taveira* itself provides a motivation to combine with *Qi*'s security techniques, explaining that because drones are "conspicuous," they may be "vulnerable to tampering," intercepting, interfering, or hijacking during flight. Ex. 1010, [0002]. Thus, a POSITA would have sought out various solutions to prevent such issues, and an obvious and known solution would be to periodically update the RF emitter's SSID or MAC address as taught by *Qi* to reduce the likelihood of an attacker to discover the SSID or MAC address and use it for illicit purposes.

175. Further, combining *Qi*'s teachings regarding periodically updating unique identifiers such as SSIDs with *Taveira*'s use of such unique identifiers in wireless communications is merely combining prior art elements (*i.e.*, periodically updating identifiers such as SSIDs, as taught by *Qi*) to known methods (*i.e.*, *Taveira*'s wireless communications system that uses unique identifiers such as SSIDs and MAC addresses) to yield predictable results (*i.e.*, producing a wireless communication system that periodically updates identifiers used in communications). Accordingly, a POSITA would have been motivated to combine *Qi*'s teachings of updating unique identifiers with *Taveira*'s wireless communication system, and would have reasonably expected success in doing so. *Id.*

2. *Taveira* with *Gong*

176. *See supra*, XII.A.2.

A. CLAIM 21

1. **21[p]: A device configured to communicate identification information associated with a low-altitude aircraft, the device comprising:**

177. *See supra*, XII.B.1.

2. **21[a]: a radio frequency communication antenna;**

178. *See supra*, XII.B.2.

3. **21[b]: a radio communication module coupled to the radio frequency communication antenna and configured to transmit identification information associated with the low-altitude aircraft through a transmitted radio signal,**

179. *See supra*, XII.B.3.

4. **21[c]: wherein the radio communication module is configured to receive a received radio signal and store the information in a storage,**

180. *See supra*, XII.B.4.

5. **21[d]: wherein the radio frequency communication antenna is coupled to the low-altitude aircraft and**

181. *See supra*, XII.B.5.

6. **21[e]: the radio communication module is configured to utilize a secure identifier,**

182. The *Taviera-Qi* combination teaches Limitation 21[e] through its description of periodically updating SSIDs that are included in wireless communications. *Taveira* describes that radio module 130 receives an RF signal from an RF emitter, where the signal includes a “unique identifier” such as a “service

sector identification (SSID), a media access control (MAC) address, radio station call sign, [or] cell ID,” and radio module 130 provides this signal to processor 120, which “use[s] that information to obtain the ground coordinates and signal strength of the detected RF emitter” from a database of RF emitter characteristics and in turn “estimate the location of the drone 100 relative to the coordinates.” Ex. 1010, [0056]. Therefore, radio module 130 (“*the radio communication module*”) is “*configured to utilize an identifier*” of an RF emitter, such as an SSID, by providing it to processor 120 so that the processor can estimate the drone’s location.

183. To the extent *Taveira* does not explicitly disclose that the identifier of the RF emitter is a “*secure identifier*,” the combination of *Taveira* and *Qi* does. *Qi* teaches a system for “securing a service Identifier (ID)” used in wireless communications between devices such as a “vehicular device” and a “server computer,” where a “Secured Service ID (SSID) is utilized to identify a Service.” Ex. 1013, Abstract, [0035], [0096]. *Qi* describes that a “Service Provider” may “distribute” a “service name key to devices 102 and/or 140...at any other time, e.g., as part of any update,” where “devices 102 and/or 140 may retrieve and/or ‘pull’ the Service name key from the ‘Service Provider’, e.g., periodically, for example as part of an update procedure or in any other manner, e.g., according to a policy.” *Id.*, [0106]-[0107]. *Qi* explains that an SSID processor 129 of a device 102 may “periodically receive an update of the service name key corresponding to the service,

e.g., from the service provide[r]” and that the “SSID processor 129 may update the SSID based on the update of the service name key.” *Id.*, [0168]-[0169]. *Qi* explains that “updating the SSID, e.g., along time, may increase the security of the SSID and/or may reduce the probability of an attacker to discover the service name of the service based on the SSID, e.g., compared to an implementation in which the SSID is kept constant.” *Id.*, [0170]. Thus, applying these teachings of *Qi* to *Taveira*’s wireless communication system (which uses SSIDs in wireless communications), the combination of *Taveira* and *Qi* would have provided that *Taveira*’s received “unique identifier,” which is an SSID or MAC address, and that is utilized by radio module 130 as discussed, is a “*secure identifier*” because the SSID (or MAC address) would have been periodically changed via updating (as opposed to being kept constant) as taught by *Qi*.

184. As I discussed in Ground 2 regarding Limitation 21[e], *Taveira* teaches Limitation 21[e] through its disclosure of receiving and processing heart beat signals that include identifying information and are encoded. *See supra*, XII.B.6. For at least those same reasons, the *Taveira-Qi* combination renders obvious Limitation 21[e].

7. 21[f]: and the radio communication module is configured for two-way communication with a remote portable detection system;

185. *See supra*, XII.B.7.

8. 21[g]: and wherein the device is coupled to the low-altitude aircraft and

186. *See supra*, XII.B.8.

9. 21[h]: the remote portable detection system includes a user interface configured to provide to a user, information associated with a plurality of different low-altitude aircrafts detected by the remote portable detection system.

187. *See supra*, XII.B.9.

XIV. GROUND 4: OBVIOUS OVER GONG AND WANG-II

A. MOTIVATION TO COMBINE

1. Gong with Wang-II

188. *Gong* discloses a UAV that includes a “flight control unit,” such as “flight control unit 410,” which comprises “identification module 410, one or more processors 420, and one or more communication modules 430.” Ex. 1012, [0233], [0235]. Further, *Gong* explains that its UAV is capable of “two-way communications” with external devices via wireless resources. *Id.*, [0648]. Apart from *Gong*’s description of the communication module/unit⁶ as the device

⁶ *Gong* uses the term “communication module” and “communication unit” interchangeably throughout its disclosure, as both terms are used to describe the component responsible for a UAV’s communication functions. *See, e.g.*, Ex. 1012, [0024] (“Aspects of the invention may also be directed to an unmanned aerial vehicle (UAV) comprising, a communication unit configured to receive or transmit wireless

responsible for such wireless communication, *Gong* does not provide detail regarding all the particular components involved in implementing wireless communications. Accordingly, a POSITA implementing *Gong* would have been motivated to seek out additional disclosures that detail the particular components involved in implementing wireless communication, such as *Wang-II*. *Wang-II* discloses a “communication terminal 1200 can be implemented by a mobile platform (e.g., UAV) or other remotely-controlled movable object capable of transmitting downlink data and receiving uplink data” in a wireless communication environment, and that such wireless communications involve the transmission of “electromagnetic signals such as electric voltage, radiowave, microwave, infrared signals, or the like.” Ex. 1014, [0060], [00141]. *Wang-II* explains that “communication terminal 1200 includes an uplink receiver 1204, a downlink transmitter 1202, and an antenna 1206.” *Id.*, [00141]. Accordingly, a POSITA would have recognized that *Wang-II* fills in the gaps left by *Gong* and would have been motivated to combine *Wang-II*’s teachings with *Gong* when implementing *Gong*’s system.

189. Further, both *Gong* and *Wang-II* were assigned to SZ DJI Technology Co., Ltd., and it would have been obvious to a POSITA to combine interrelated

communications;...”), [0195] (“A UAV may comprise:...a communication module configured to receive one or more flight commands from a remote user;...”).

teachings of patents of the same company. *See* Ex. 1012, item (71); *see also* Ex. 1014, item (71).

190. Further, combining *Gong* with *Wang-II* is merely combining prior art elements (*i.e.*, *Wang-II*'s uplink receiver 1204, downlink transmitter 1202, and antenna 1206) to known methods (*i.e.*, *Gong*'s wireless communication technique using the communications module/unit) to yield predictable results (*i.e.*, two-way wireless communications by the communications module/unit).

191. Accordingly, a POSITA would have been motivated to combine *Gong* and *Wang-II*, and would have had a reasonable expectation of success in doing so.

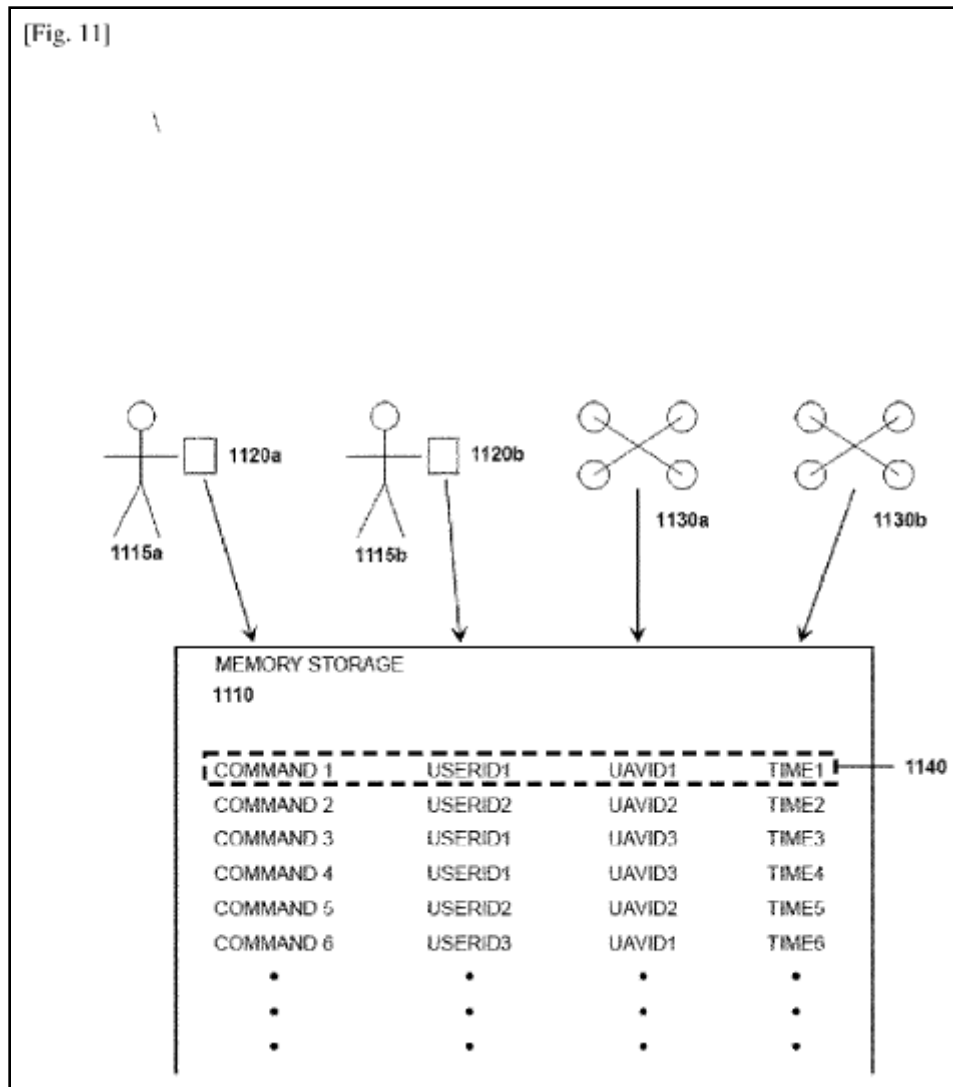
B. CLAIM 21

1. 21[p]: A device configured to communicate identification information associated with a low-altitude aircraft, the device comprising:

192. To the extent the preamble is limiting, *Gong* teaches the preamble at least through its disclosure of flight control unit 410, which communicates unmanned aerial vehicle (UAV) identifier information. *Gong* discloses a UAV that includes a “flight control unit,” such as “flight control unit 410,” which comprises “identification module 410, one or more processors 420, and one or more communication modules 430.” Ex. 1012, [0233], [0235]. “The identification module may be able to uniquely identify and differentiate the UAV from other UAVs,” and “may comprise a UAV identifier and a key of the UAV.” *Id.*, [0236].

Gong explains that the “UAV identifier may be unique to the UAV” and “may uniquely differentiate and/or distinguish the UAV from other UAVs.” *Id.*, [0133]. Further, “[a] UAV may broadcast the UAV identifier during operation.” *Id.*, [0277]. *Gong* explains that the “flight control unit may control communications of the UAV.” Ex. 1012, [0234]. In particular, *Gong* explains that the communications module/unit is “configured to receive or transmit wireless communications.” Ex. 1012, [0024].

193. Further, a POSITA would have understood that *Gong*’s UAV is a “*low-altitude aircraft*.” *Gong* explains that its UAV “may be a rotorcraft” that comprises multiple rotors that are “capable of rotating to generate lift for the UAV.” Ex. 1012, [0126]. Also, *Gong*’s UAV may be prevented “from flying above an altitude ceiling that may be fixed or variable.” *Id.*, [0173]. And throughout the figures of *Gong*, such as Figure 11, annotated below, UAVs are depicted as 4-rotor drones, which a POSITA would have understood to be “*low-altitude aircraft*.”



Ex. 1012, Fig. 11 (annotated to identify UAVs 1130).

194. This understanding of *Gong*'s UAVs as “*low-altitude aircraft*” is consistent with the '959 Patent, which acknowledges that a “drone” is an example of a “low altitude aircraft.” See Ex. 1001, 12:61-62, Fig. 12 (depicting drone 1214 as a 4-rotor aircraft).

195. Accordingly, *Gong* discloses that flight control module 410 (“[a] device”) is configured to communicate, through communication module/unit 430, a

UAV identifier that uniquely identifies the associated UAV (“*identification information associated with a low-altitude aircraft*”).

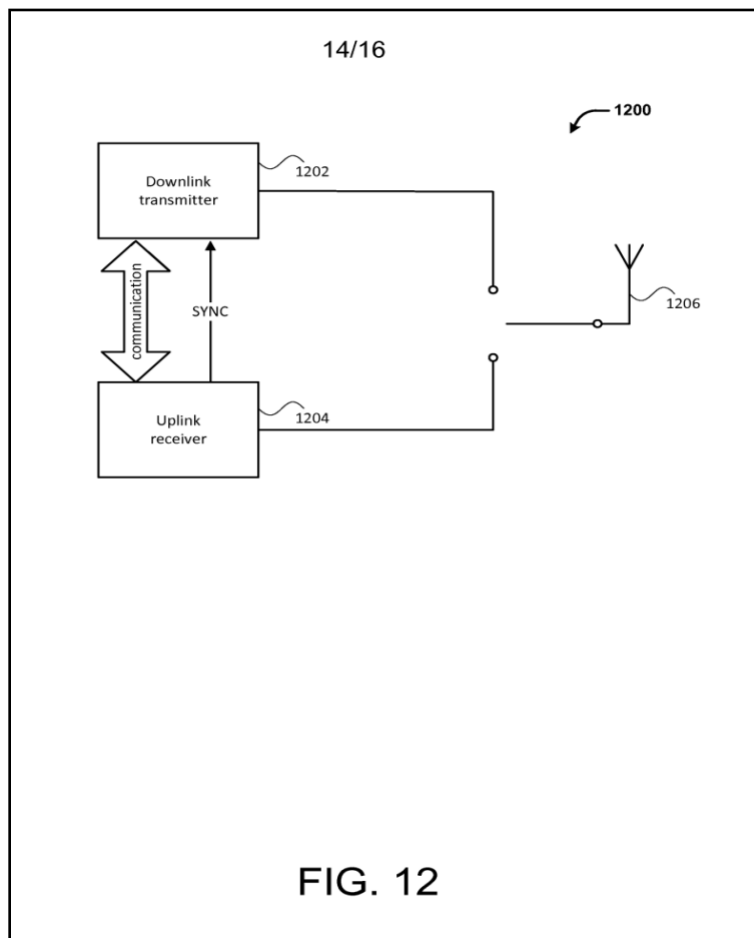
2. 21[a]: a radio frequency communication antenna;

196. *Gong* teaches Limitation 21[a] at least through its disclosure of communicating wirelessly via radio signals. In the alternative, the *Gong-Wang-II* combination teaches Limitation 21[a] through its disclosure of antenna 1206.

197. As discussed above with reference to Limitation 21[p], *Gong* explains that its flight control unit, through the communication module/unit, is capable of wireless communication. *See supra*, XIV.B.1. An example of such communication is when *Gong*’s UAV broadcasts an associated UAV identifier: *Gong* explains that such information “may be broadcasted via a wireless signal (e.g., radio signal, optical signal, or an acoustical signal).” Ex. 1012, [0271]. Accordingly, a POSITA would have understood that *Gong*’s communications module/unit includes an antenna capable of transmitting radio signals (“*a radio frequency communication antenna*”) to perform such broadcasting. Accordingly, *Gong* teaches Limitation 21[a].

198. In the alternative, the *Gong-Wang-II* combination renders Limitation 21[a] obvious. Like *Gong*, *Wang-II* discloses a “communication terminal 1200 can be implemented by a mobile platform (e.g., UAV) or other remotely-controlled movable object capable of transmitting downlink data and receiving uplink data” in

a wireless communication environment, and that such wireless communications involve the transmission of “electromagnetic signals such as electric voltage, radiowave, microwave, infrared signals, or the like.” Ex. 1014, [0060], [00141]. *Wang-II* explains that “communication terminal 1200 includes an uplink receiver 1204, a downlink transmitter 1202, and an antenna 1206.” Id., [00141].



Ex. 1014, Fig. 12.

199. Accordingly, the *Gong-Wang-II* combination, which renders obvious incorporating *Wang-II*'s antenna in *Gong*'s communications unit/module to facilitate wireless communication, teaches Limitation 21[a].

3. **21[b]: a radio communication module coupled to the radio frequency communication antenna and configured to transmit identification information associated with the low-altitude aircraft through a transmitted radio signal,**

200. *Gong* teaches Limitation 21[b] at least through its disclosure of the communications module/unit. In the alternative, the *Gong-Wang-II* combination renders obvious Limitation 21[b] at least through *Gong*'s disclosure of the communication module/unit as coupled to *Wang-II*'s antenna 1206.

201. As discussed above with reference to Limitations 21[p] and 21[a], *Gong* discloses broadcasting, by a UAV, a "UAV identifier" that "may uniquely differentiate and/or distinguish the UAV from other UAVs" via "a wireless signal (e.g., radio signal,...)." *See supra*, XIV.B.1-2; Ex. 1012, [0133], [0236], [0271]. Further, *Gong* discloses that the communications module/unit is the component responsible for wireless transmissions from the UAV. *See supra*, XIV.B.1; Ex. 1012, [0024]. Accordingly, *Gong* discloses that its communications module/unit ("a radio communication module") is configured to transmit UAV identifiers via radio signals ("identification information associated with the low-altitude aircraft through a transmitted radio signal"). Further, a POSITA would have understood that communication module/unit's use of radio signals for such transmission indicates that the communication module/unit is coupled to a "radio frequency communication antenna," which a POSITA would have understood to be a necessary component for such wireless communications. *See supra*, XIV.B.2 (discussing POSITA's

understanding of inclusion of a “*radio frequency communication antenna*” in Gong’s UAV).

202. In the alternative, the *Gong-Wang-II* combination renders obvious Limitation 21[b]. As discussed above with reference to Limitation 21[a], *Wang-II* discloses a UAV that includes a “communication terminal 1200,” which includes an uplink receiver 1204, a downlink transmitter 1202, and an antenna 1206.” A POSITA would have understood that under the *Gong-Wang-II* combination, Gong’s communications module/unit (“*a radio communication module . . . configured to transmit identification information associated with the low-altitude aircraft through a transmitted radio signal*”) would comprise *Wang-II*’s “uplink receiver 1204” and “downlink transmitter 1202” and would be coupled to *Wang-II*’s “antenna 1206” (“*coupled to the radio frequency communication antenna*”) as such components would be obvious components for effectuating the wireless signal transmission and reception functionality of Gong’s communication module/unit. Accordingly, the *Gong-Wang-II* combination renders obvious Limitation 21[b].

4. 21[c]: wherein the radio communication module is configured to receive a received radio signal and store the information in a storage.

203. *Gong* teaches Limitation 21[c] at least through its disclosure of receiving UAV identifier information and storing such information in an identification module.

204. As discussed above with reference to Limitation 21[p], *Gong* explains that “identification module 410,” which, along with communication unit/module, is part of a flight control unit aboard a UAV, may comprise “a UAV identifier” that “uniquely differentiate[s] and/or distinguish[es] the UAV from other UAVs.” *See supra*, XIV.B.1; Ex. 1012, [0133], [0233], [0235], [0236]. *Gong* explains that the UAV identifier “may be issued by an ID registration database,” which “may be off-board the UAV.” Ex. 1012, [0240]. Further, *Gong* provides that the “identification module may be configured to receive the UAV identifier.” *Id.* Because *Gong* discloses that reception of data from off-board devices is handled by the communication module/unit via radio signals, a POSITA would have understood that the identification module “receives the UAV identifier” via radio signals first received by communications module/unit. Further, *Gong* discloses that the “UAV identifier may be stored in the identification module in an unalterable state” once configured. Ex. 1012, [0237]. Accordingly, *Gong* discloses that the communications module/unit (“*the radio communication module*”) is configured to receive a UAV identifier via a radio signal (“*configured to receive a received radio signal*”) and store the received UAV identifier in the identification module (“*store the information in a storage*”).⁷

⁷ As noted above in Footnote 4, this interpretation is consistent with Patent Owner’s interpretation of the claim as indicated in the parallel district court case.

5. 21[d]: wherein the radio frequency communication antenna is coupled to the low-altitude aircraft and

205. As discussed above with reference to Limitation 21[a], *Gong* suggests to a POSITA that its communications unit/module includes an antenna capable of transmitting radio signals in view of *Gong*'s disclosure of communications module/unit performing wireless communications. *See supra*, XIV.B.2. And because the communications module/unit is included in a UAV (as a component of the flight control unit), a POSITA would have understood that the antenna (“*the radio frequency communication antenna*”) would also be coupled to the UAV (“*the low-altitude aircraft*”). Ex. 1012, [0233] (explaining that the flight control unit is included in the UAV), [0235] (explaining that the communications module/unit is included in the flight control unit). Accordingly, *Gong* teaches Limitation 21[d].

206. In the alternative, the *Gong-Wang-II* combination renders obvious Limitation 21[d]. As discussed above with reference to Limitation 21[a], it would have been obvious to a POSITA to incorporate *Wang-II*'s antenna (e.g., antenna 1206) in *Gong*'s communications module/unit to facilitate communication module/unit's wireless communication functionalities. *See supra*, XIV.B.2. And because the communications module/unit is included in a UAV (as a component of the flight control unit), a POSITA would have understood that the antenna (“*the radio frequency communication antenna*”) would also be coupled to the UAV (“*the low-altitude aircraft*”). Ex. 1012, [0233] (explaining that the flight control unit is

included in the UAV), [0235] (explaining that the communications module/unit is included in the flight control unit).

6. 21[e]: the radio communication module is configured to utilize a secure identifier,

207. *Gong* teaches Limitation 21[e] at least through its disclosure of broadcasting its UAV identifier over encrypted signals. As discussed above with reference to Limitations 21[p] and 21[b], *Gong*'s communications unit/module is configured to broadcast (“*utilize*”) a UAV identifier (“*a[n] . . . identifier*”) via radio signals. *See supra*, XIV.B.1, XIV.B.3. Further, *Gong* explains that the “UAV identifier may be broadcasted when a communication between the UAV and the air control system may be encrypted or authenticated.” Ex. 1012, [0271]; *see also id.*, [0487] (“In some embodiments, encryption of communications may occur.”). Accordingly, *Gong* teaches that the UAV identifier is “secured” through encryption when it is broadcasted. Thus, *Gong* teaches that the communications module/unit (“*the radio communication module*”) is configured to broadcast (“*is configured to utilize*”) an encrypted UAV identifier (“*a secure identifier*”).

7. 21[f]: and the radio communication module is configured for two-way communication with a remote portable detection system;

208. *Gong* teaches Limitation 21[f] at least through its disclosure of communication module/unit's two-way communication with a geo-fencing device. *Gong* discloses that “a UAV device may establish communications with [a] geo-

fencing device and an exchange of information may occur,” and that such communications “may include one-way communications or two-way communications.” Ex. 1012, [0648] (listing “UAV identity, geo-fencing device identity, UAV type, geo-fencing device type, UAV location, geo-fencing device location, geo-fencing device type of boundary, flight regulations, or any other type of information,” as examples of the information exchanged between the devices). Because *Gong* explains that its communications module/unit is responsible for the UAV’s wireless signal transmission and reception, a POSITA would have understood that the communications module/unit (“the radio communication module”) is “configured for two-way communication.” *See, e.g.*, Ex. 1012, [0024] (“Aspects of the inventions may also be directed to an unmanned aerial vehicle (UAV) comprising: a communication unit configured to transmit or receive wireless communications;...”).

209. *Gong*’s “geo-fencing device” discloses “a remote portable detection system.” *Gong* describes a “remote device” that may be a “remote controller” that communicates with a UAV using “wireless communications” such as “WiFi” and “radio” and that shows on a display “a location of [] [a] first UAV” and “may...show a location of [] [a] second UAV.” Ex. 1012, [0182] (describing UAV’s “remote communication with one or more remote devices.”), [0955]. The “location of a UAV shown on the remote device may be updated in real-time.” *Id.*, [0957]. Moreover,

Gong describes that its remote controller can be implemented as a “geo-fencing device” that “detect[s] the presence of the UAV” and that the geo-fencing device can be “portable.” *Id.*, [0593] (“Alternatively, the geo-fencing device may be easily movable and/or portable.”), [0600] (“In some embodiments, the geo-fencing device may be a remote controller configured to receive a user input.”), [0628] (“The geo-fencing device may be able to detect the presence of the UAV...”); *see also id.*, [0137] (describing the remote controller “may be a...mobile device” such as a “smartphone, cellular phone, [or] tablet.”). The geo-fence device further interacts with multiple UAVs, providing a “reference point for different sets of flight regulations for different UAVs in different circumstances that may approach the geo-fencing device.” *Id.*, [0864]-[0869].

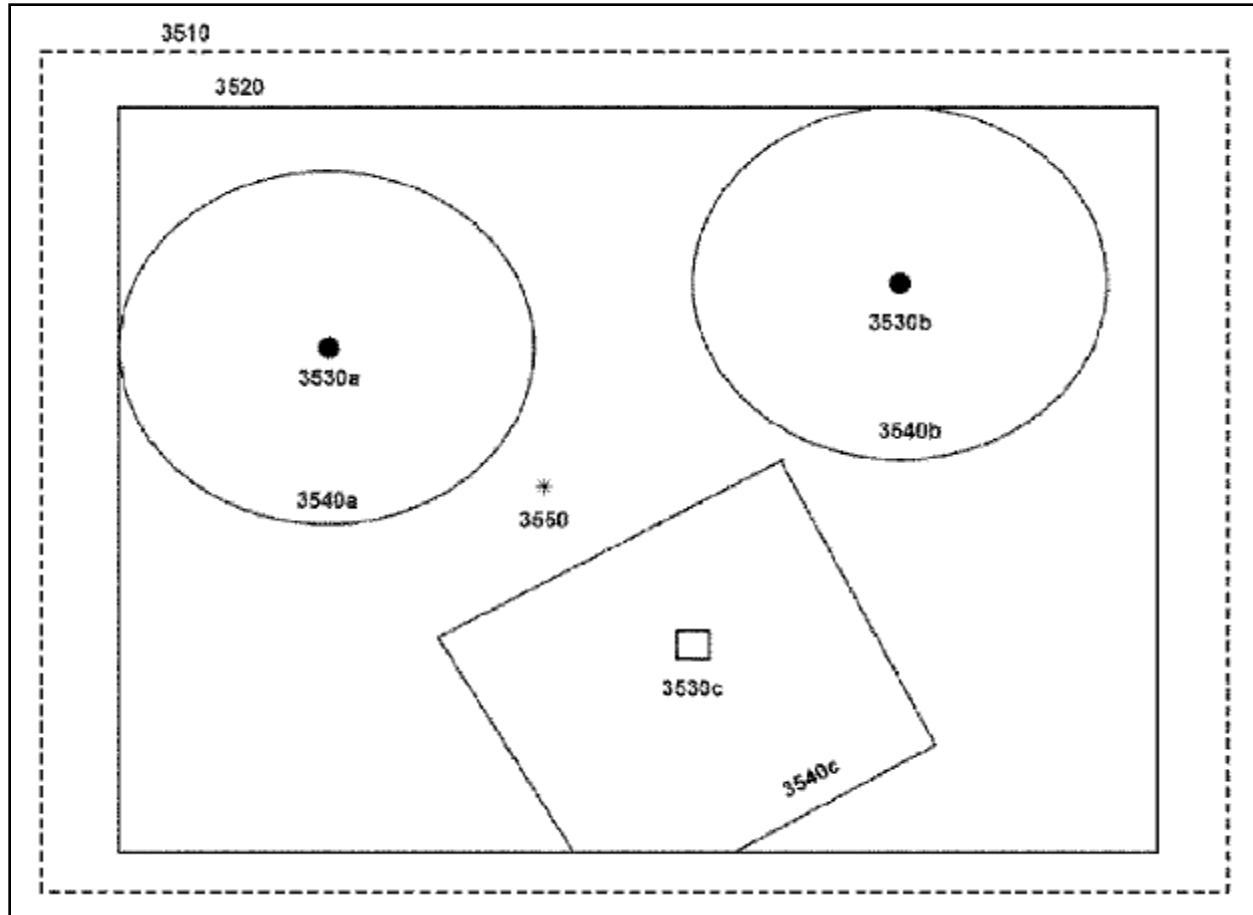
210. Accordingly, *Gong*’s disclosure regarding communication module/unit’s (“the radio communication module”) two-way communications with a geo-fencing device (“two-way communication with a remote portable detection system”) teaches Limitation 21[f].

8. 21[g]: and wherein the device is coupled to the low-altitude aircraft and

211. As discussed above with reference to Limitation 21[p], *Gong* discloses that its flight control unit (“*the device*”) is included in the UAV (“*the low-altitude aircraft*”). *See supra*, XIV.B.1. Thus, *Gong*’s flight control unit is coupled to the UAV and teaches Limitation 21[g].

9. 21[h]: the remote portable detection system includes a user interface configured to provide to a user, information associated with a plurality of different low-altitude aircrafts detected by the remote portable detection system.

212. *Gong* teaches Limitation 21[h] at least through its disclosure of a geo-fencing device that can display information about multiple detected UAVs. *Gong* describes a “remote device” that shows on a display “a location of [] [a] first UAV” and “may...show a location of [] [a] second UAV.” Ex. 1012, [0182], [0955]. The “location of a UAV shown on the remote device may be updated in real-time.” Id., [0957]. And as discussed above with reference to Limitation 21[f], *Gong* describes that its remote controller can be implemented as a “geo-fencing device” that “detect[s] the presence of the UAV” and that the geo-fencing device can be “portable.” *See supra*, XIV.B.7; Ex. 1012, [0137], [0593], [0600], [0628]. The geo-fence device further interacts with multiple UAVs, providing a “reference point for different sets of flight regulations for different UAVs in different circumstances that may approach the geo-fencing device.” Ex. 1012, [0864]-[0869]. Figure 35 of *Gong*, copied below, shows an example of such user interface that displays the location of a UAV 3550 and geo-fencing devices 3530:



Ex. 1012, Fig. 35.

XV. SECONDARY CONSIDERATIONS

213. I am not aware of any evidence of secondary considerations that would support a finding of nonobviousness of the '959 Patent. Should the Patent Owner put forth any alleged evidence of secondary considerations, I reserve the right to consider such evidence, to consider whether any such evidence has a nexus to any claims of the '959 Patent, and to update my analysis.

XVI. CONCLUSION

214. All statements made herein of my own knowledge are true, and all statements made on information and belief are believed to be true. I further understand that willful false statements and the like are punishable by fine or imprisonment, or both under Section 1001 of Title 18 of the United States Code. I declare under penalty of perjury that the foregoing is true and correct.

Executed on January 28, 2025.



Dr. Girish Chowdhary

Appendix A

Girish Chowdhary

girishc@illinois.edu, 404-409-8518, 2003 Mullikin Drive, Champaign, IL 61822

1. PERSONAL HISTORY AND PROFESSIONAL EXPERIENCE

I. Educational Background

Royal Melbourne Institute of Technology	Aerospace Engineering	B.E. Hons. 2003
Georgia Institute of Technology	Aerospace Engineering	M.S. 2008
Georgia Institute of Technology	Aerospace Engineering	Ph.D. 2010

B. List of Academic Positions since Final Degree

Associate Professor, Donald Biggar Willet Faculty Fellow, ACES Office of Research Fellow
University of Illinois at Urbana-Champaign, Department of Agricultural and Biological Engineering *and* Department of Computer Science (*joint appointment*), Coordinated Sciences Lab (full member), Department of Aerospace Engineering (affiliate), Department of Electrical and Computer Engineering (affiliate)

Director, Distributed Autonomous Systems (DAS) Lab, and Field Robotics Science and Engineering Hub (FRESH)

Director, USDA Farm of the Future: I-FARM testbed

Director, USDA-NRES Biden Harris Climate Smart Commodities Grant: I-COVER

Associate Director of Research, AI-FARMS National AI Institute

2020-

Assistant Professor

University of Illinois at Urbana-Champaign, Department of Agricultural and Biological Engineering (home), Coordinated Sciences Lab (full member), Department of Computer Science (affiliate), Department of Aerospace Engineering (affiliate), Department of Electrical and Computer Engineering (affiliate), Institute of Genomic Biology (affiliate)

2016-2020

Assistant Professor

Oklahoma State University, School of Mechanical and Aerospace Engineering

2013-2016

Visiting Professor

Massachusetts Institute of Technology, Laboratory for Information and Decision Systems (LIDS)

Summer 2013

Postdoctoral Associate

Massachusetts Institute of Technology, Laboratory for Information and Decision Systems (LIDS), School of Aeronautics and Astronautics

2011-2013

Research Engineer II,

Georgia Institute of Technology, School of Aerospace Engineering

2010-2011

Postdoctoral Researcher,

Georgia Institute of Technology, School of Aerospace Engineering

2010-2010

C. Other Professional Employment

Chief Technology Officer and co-founder,

EarthSense Inc., Champaign, Illinois

2016-

VP of Autonomous Systems and co-founder

Unmanned Cowboys LLC, Stillwater, Oklahoma

2015-2016

Research Engineer,

The German Aerospace Center (DLR), Braunschweig, Germany

2004-2006

D. Honors, Recognitions, and Outstanding Achievements

1. **Illinois Innovation Network Award**, Food and Agriculture Category, Aug 2021
2. UIUC Campus internal competition for Blavatnik award nomination, August 2021
3. **ACES Office of Research Faculty Fellow**, University of Illinois at Urbana Champaign, College of Agricultural and Consumer Economics Sciences (ACES), 08/16/2020 – 08/15/2023
4. **Donald Biggar Willet Faculty Fellow**, University of Illinois at Urbana Champaign, Grainger College of Engineering, 08/16/2020 – 08/15/2023
5. **Dean's award for Excellence in Research**, University of Illinois at Urbana Champaign, Grainger College of Engineering, April 2020.
6. **Campus Insight presentation to the UIUC Board of Trustees**, University of Illinois Urbana Champaign, March 2020
7. Principle Investigator on Office of Naval Research prestigious Multi University Research Initiative (**MURI**) grant: A Cyberoctopus that learns, evolves, and adapts, 2019.
8. **Dave Ward Memorial award** by Aerospace Control Guidance and Systems Group (ACGSC) for outstanding contributions to Aerospace GNC, 2015
9. Recipient of the Air Force Office of Scientific Research (**AFOSR**) **Young Investigator Research Program (YIP)** award (AFOSR's most prestigious young faculty grant), 2015
10. Recipient of **best systems paper award at the 2018 Robotics Science and Systems** conference
11. Recipient of **best paper award** at the 2012 AIAA Guidance Navigation and Control Conference, out of over 600 papers
12. **Associated Fellow** (by nomination), American Institute of Aeronautics and Astronautics, 2017
13. **Senior Member** (elected), Institute of Electrical and Electronics Engineers, 2017
14. Sponsored **visiting professor** at The Institute of Flight Systems Dynamics of the Technical University of Munich, Summer 2014
15. Leader of the Georgia Tech Team that stood first overall, first in outdoor autonomy, and first in outdoor flight dynamics in the 2011 IMAV competition
16. Leader of the Georgia Tech Aerial Robotics Team that stood first in the 2010 AUVSI International Aerial Robotics Competition (IARC)

E. Invited Lectures and Invited Conference Presentations

1. Where are the Field Robots, Stanford Robotics Seminar, December 2024.
2. Farms of the Future, Lessons from the US MidWest, invited talk in Vision for Ag at CVPR 2024, June 2024.
3. Advancing AI for Agricultural and Environmental Sustainability, Cornell University, NY, May 2024
4. Advancing AI for Autonomous Field Robots, University of Florida, FL, March 2024
5. Small Robots for All Farms, Future of Agriculture Symposium, organized by Mahtma Phule Krishi Vidyapith (prominent agricultural university in India), Pune, December 2023
6. AIFARMS view on Digital Agriculture in India, Workshop on Digital Agriculture at the IEEE HiPC conference, Goa, India, December 2023
7. Farms of the Future, a View from Under the Canopy, Corteva Plant Sciences Symposia Series, "DA3: Digital Agriculture and Advanced Analytics – Innovation to the Service of Farmers", Kansas State University, October 2023
8. Farms of the Future for Saudi Arabia: Lessons from the US MidWest, King Abdullah University of Science and Technology (KAUST), Saudi Arabia, May 2023
9. The robots are coming to your farm to plant cover crops, US Soybean Research Collaborative, April 2023
10. Shell.AI Upskilling series: AI Advances for Field Robotics, July 2022
11. The robots are coming to you farm: Autonomous and Intelligent Robots in Unstructured Field Environments, Phenorob center of excellence, Bonn University, July 2022.
12. The robots are coming to you farm, Michigan State University, Robotics and Control Seminar, November 2021.

13. The robots are coming to your farm, ICT Applications in Agriculture, Agricultural College NAIRA, Andhra Pradesh, India, October 2021.
14. IoT for Agriculture, IoT Day @ ACM MobiSys 2021, June 2021
15. The robots are coming to your farm, King Abdullah University of Science and Technology (KAUST) research conference on robotics and autonomy, April 2021
16. The robots are coming to your farm, Berkeley Sankar Sastry Semi-Autonomous Seminar, March 2021
17. Keynote speaker, SEMATRON National Symposium on Mechatronics from Undergraduate Students, Brazil chapter webinar, Nov 2020
18. Invited speaker: IEEE Robotics and Automation Society (RAS) SB Webinar, Nov 2020
19. Invited speaker: RSS workshop 'Robots in the Wild: Challenges in Deploying Robust Autonomy for Robotic Exploration', July 2020, Robotics Science and Systems conference, (held online due to COVID-19)
20. Invited speaker in the AAAS Policy Fellows symposium, Living with AI: The Human Impacts of AI, Interactive Panel: The Role of AI in Producing Your Produce, June 2020 (held online due to COVID-19)
21. Tackling the herbicide resistant weed crisis with teams of mechanical weeding agbots, Weed Science Society of America (WSSA) annual Symposium, Maui, HI, March 2020
22. The Robots are Coming, to Your Farms, Carnegie Mellon Robotics Institute (RI) seminar, Nov 2019
23. The Robots are Coming, to Your Farms, Massachusetts Institute of Technology, LIDS seminar, September 2019
24. The Robots are Coming, to Your Farms, Brown University, Robotics Talk, March 2019
25. Compact and Autonomous robots for High-Throughput Phenotyping, invited talk at 2019 Genomes to Fields collaborator meeting at Phenome conference, January 2019
26. Autonomous and Intelligent Robots in Unstructured Field Environments, Zhejiang University, Invited lecture, College of Agriculture and Biotechnology, Hangzhou, China, July 2018
27. Autonomous and Intelligent Robots in Unstructured Field Environments, Bio Robotics conference at the China Agricultural University, invited semi-plenary speech, Beijing, China, July 2018
28. Autonomous and Intelligent Robots in Unstructured Field Environments, Robotics Seminar, Cornell University, April 2018
29. The Robots are Coming, to Your Farm, Iowa State, INTRANS seminar, March 2018
30. The Robots are Coming, to Your Farm, Iowa State, Department of Aerospace Engineering seminar, March 2018
31. The Robots are Coming – For your Food, Colorado State University, Sept 2017
32. Differentially Constrained Machine Learning for Distributed Autonomy, United Technologies Research Center (UTRC), Feb 2017
33. Differentially Constrained Machine Learning, Coordinated Science Laboratory Decision and Control Seminar, University of Illinois at Urbana Champaign, Nov 2016
34. Hardware-in-the-Loop Simulation for UAS Research, Workshop on Realistic Rapid and Repeatable Robot Simulations (R4SIM), Robotics Science and Systems Conference, July 2015
35. Algorithms for Data-Driven Monitoring of Massive Scaled Spatiotemporal Processes with Unmanned Aerial Systems, IEEE Real-Time Computing and Robotics Conference (RCAR), June 2015, *Keynote speech*
36. Systems Theoretic Bayesian Machine Learning for Autonomous Decision Making over Massive Spatiotemporal Scales, Georgia Institute of Technology, Institute of Robotics and Intelligent Machines seminar, May 2015.
37. Data-Driven Adaptive Systems for Robust Autonomy, Stanford Department of Aeronautics and Astronautics, San Jose, CA, December 2014.
38. Data-Driven Autonomous Monitoring of Massive Scaled Spatiotemporal Processes, Massachusetts Institute of Technology, Laboratory of Information and Decision Systems, Cambridge, MA, December 2014

39. Data-Driven Autonomous Monitoring of Massive Scaled Spatiotemporal Processes, The Lincoln Lab at Massachusetts Institute of Technology, Lexington, MA, December 2014.

F. Offices Held in Professional Societies

1. IEEE (Institute of Electrical and Electronics Engineers), Senior Member (elected), Robotics and Automation Society member, Control Systems Society member, Technical Committee on System Identification member,
2. AIAA (American Institute of Aeronautics and Astronautics) Associate Fellow (by nomination) Guidance, Navigation, and Control Committee member, AIAA Intelligent Systems Committee, member
3. ASABE (American Society of Agricultural and Biological Engineers), member, committee member representing ASABE on IFAC (International Federation of Automatic Control) Control in Agriculture committee

G. Editorships of Journals or Other Publications

1. **IEEE Transactions on Neural Networks and Learning Systems** (TNNLS, impact factor 11.683), associate editor, Jan 2018-
2. **AIAA Journal of Aerospace Information Systems**, Guest Editor for Special Issue on Estimation and Information Theory Applications for Resilient and Distributed Operation of Aerospace Systems, with Girish Chowdhary (lead), Raj Sharma, Adam Rutkowski
3. **AIAA Journal of Aerospace Information Systems**, Guest editor for Special issue on applications of Reinforcement Learning and Learning Based Adaptive Control to Mechanical and Aerospace Systems, with J. P. How (lead), Alborz Gerafard, Thomas Walsh, Nicholas Roy
4. **AIAA Guidance Navigation and Control Conference**, associate editor 2017, 18, 19
5. **IEEE Conference on Decision and Control**, associate editor 2018

H. Review committees for peer-reviewed conferences

1. Robotics Science and Systems (**RSS**): Since 2014
2. International Conference on Robotics and Automation (**ICRA**): Since 2012
3. International Conference on Intelligent Robots and Systems (**IROS**): Since 2010
4. Neural Information processing Systems (**NeurIPS**): Since 2015
5. International Conference on Machine Learning (**ICML**): Since 2015
6. Control and Decision Making: IEEE Conference on Decision and Control (**CDC**): Since 2008
7. American Control Conference (**ACC**): Since 2008
8. Reinforcement Learning and Decision Making (**RLDM**): 2013, 14, 16
9. AIAA Guidance Navigation and Control Conference (**GNC**) now part of AIAA SciTech Forum: Since 2009

I. Grants Received

Principal Investigator (PI), Co-P Investigator (Co-PI)	Funding Agency	Title	Funding Year(s)	Total Funding	Funding Specific to Candidate
Competitive External Funding					

Principal Investigator (PI), Co-P Investigator (Co-PI)	Funding Agency	Title	Funding Year(s)	Total Funding	Funding Specific to Candidate
PI: G. Chowdhary Co-PIs: Di Fulvio A., Atallah S., Soman C., Quansah J., Schange R.	USDA/N RCS	iCOVER: Innovative Cover-crop Opportunity, Verification, and Economy stimulating technology for underserved farmers using Robotics	2023-2027	\$4,999,999	\$400,000
PI. G. Chowdhary CO-PIs: K. Guan, I. Condotta, M. Khanna, D. Vashishth, V. Adve, S. Atallah, D. K. Lee, A. Margenot	NIFA	Supplement to: I-FARM: Illinois Farming and Regenerative Management Testbed (NIFA Farm of the Future)	2023-2025	\$370,000	\$50,000
PI. G. Chowdhary CO-PIs: K. Guan, I. Condotta, M. Khanna, D. Vashishth, V. Adve, S. Atallah, D. K. Lee, A. Margenot	NIFA	I-FARM: Illinois Farming and Regenerative Management Testbed (NIFA Farm of the Future)	2022-2025	\$3,936,000.00	\$300,000
PI: G. Chowdhary Co-PIs: K. Hauser, G. Krishnan, R. Mittal Collaborative proposal with Iowa State, Iowa State PI: S. Sarkar, Co-PIs: B. Ganapatisubramanyam (Iowa State), A. Singh (Iowa State), N. Merchant (Arizona State), A. Johri (George Mason)	NSF-NIFA	CPS: Frontier: Collaborative Research: COALESCE: COntext Aware LEarning for Sustainable CybEr-agricultural systems	2021-2026	2,000,000 (to UIUC) 5,000,000 (to Iowa state)	500,000
PI: G. Chowdhary Co-PIs: H. Tran, Sreenivas Ramavarappu, J. Yedetore, H. Fillippini	ARL	Robust and Adaptive Autonomy for Multi-Agent Maneuvers (RAAMM)	2020-22	\$865,755	\$288,000
PI: G. Chowdhary Co-PIs: H. Tran, Sreenivas Ramavarappu, J. Yedetore, H. Fillippini	CERL	RAIDE: Robust Autonomy in Denied Environments, Option 1	2020-21	\$723,783	\$369,656

Principal Investigator (PI), Co-P Investigator (Co-PI)	Funding Agency	Title	Funding Year(s)	Total Funding	Funding Specific to Candidate
PI: G. Chowdhary Co-PIs: M. Gazzolla, P. Mehta, R. Gillette (UIUC), I. Solstestz, W Gilly (Stanford), J. Rogers (NorthWestern)	ONR	A <i>Cyberoctopus</i> that Learns, Evolves, and Adapts	2019-24	\$7,500,000	\$1,420,000
PI: G. Chowdhary Co-PIs: H. Tran, Sreenivas Ramavarappu, J. Yedetore, H. Fillippini	CERL	RAIDE: Robust Autonomy in Denied Environments	2019-20	\$400,459	\$200,000
PI: G. Chowdhary Co-PIs: G. Krishnan, M. Gazzolla, S. Lovell	NSF-USDA	NRI:INT: Multipurpose Dexterous Soft and Continuum Arms for Compact Ag-bots	2018-21	\$899,998	\$300,000
PI: G. Chowdhary Co-PIs: Adam Davis, R. Srikant, Chinmay Soman	NSF-USDA	CPS: Medium: Robust Deep-Learning and Decision-Making for Mechanical Weeding Agbots	2018-21	\$885,168	\$295,056
PI: G. Chowdhary Co-PIs: Christopher Crick, Charles Abramson, Prabhakar Pagilla	NSF	NRI: Collaborative Goal and Policy Learning from Human Operators of Construction Co-Robots	2015-18	\$900,000	\$300,000
PI: G. Chowdhary	NSF	I-Corps: Online Image Analysis and Dynamic Mission Planning for Unmanned Aerial Vehicles	2017-18	\$50,000	\$50,000
PI: G. Chowdhary	AFOSR	Young Investigator Proposal: Robust Adaptive Autonomy in Contested Environments	2015-18	\$365,655	\$365,655
PI: G. Chowdhary	Sandia	Robust Autonomy in Contested Environments	2017-19	\$160,000	\$160,000
PI: G. Chowdhary	Sandia	Fault-Tolerant Adaptive Control for Over Actuated Aircraft	2018-2020	\$150,000	\$150,000

Principal Investigator (PI), Co-P Investigator (Co-PI)	Funding Agency	Title	Funding Year(s)	Total Funding	Funding Specific to Candidate
PI: G. Chowdhary	NASA	Adaptive Multi-Objective Optimization Control for Active Wing Shaping on Efficient Lightweight Transport Aircraft	2014	\$35,515	\$35,515
PI: E. Soltanaghai Co-PIs: Alipour M., Chowdhary G. , Gabriel R., Watts A.	NASA	UAS-Mounted Canopy Penetrating Radar-Tag System for Understory Fuel Sensing	2025-2028	\$1,893,864	\$250,00
PI: G. Krishnan Co-PIs: G. Chowdhary , Uppalapati N., Ahers K., Shady A.	NIFA	Robotics Integrated High Tunnels (RobInHighTs): Creating Profitable food oases in Urban ecosystems	2023-2026	\$975,000	\$360,000
PI: S. McCouch, M. (Cornell) Jose (Cornell), S. Moose (UIUC), R. Mosher (U. Arizona), A. Stook (Cornell), and others including G. Chowdhary	NSF	Center for Research on Programmable Plant Systems (CROPPS)	2021	\$25,000,000	\$280,000
PI: V. Adve, Co-PI: L. Ainsworth, G. Chowdhary , S. Guha (U. Chicago), T. Mockler (Danforth)	NSF-NIFA	AI Institute: Artificial Intelligence for Future Agricultural Resilience, Management, and Sustainability (AIFARMS)	2020-25	\$20,000,000	\$525,000
PI: C. Soman (EarthSense Inc.), Co-PI: G. Chowdhary	NSF	SBIR Phase I: TerraSentia: Ultra-compact, Autonomous, Teachable Under-canopy Phenotyping Robot for Plant Breeders and Crop Scientists	2018-19	\$225,000	\$75,000

Principal Investigator (PI), Co-P Investigator (Co-PI)	Funding Agency	Title	Funding Year(s)	Total Funding	Funding Specific to Candidate
PI: C. Soman (EarthSense Inc.), Co-PI: G. Chowdhary , V. Adve	NSF	STTR Phase II: TerraSentia: Ultra-compact, Autonomous, Teachable Under-canopy Phenotyping Robot for Plant Breeders and Crop Scientists	2020-22	\$750,000	\$228,558
PI: C. Soman (EarthSense Inc.), Co-PI: G. Chowdhary , K. Hauser	NSF	STTR Phase I: Autonomous disinfecting robot for crowded spaces Source of Support	2020-21	\$256,000	\$80,377
PI: H. Tran, Co-PIs: G. Chowdhary , Sreenivas Ramavarappu	ONR	Explainable AI for Mission Planning and Execution with Interpretable Courses of Action	2020-22	\$899,069	\$200,000
PI: H. Tran, Co-PIs: G. Chowdhary , Sreenivas Ramavarappu, H. Filippini, J. Yedetore	DARPA	A Demonstration Platform for Dynamic Mission Planning with Multi-Domain Autonomous Systems	2018-2018	\$250,458	\$200,000
PI: S. Long Co-PIs: University of Illinois (G. Chowdhary , D. Ort, P. Brown, C. Bernacchi, K. Guan, D. LeBauer), Cornell University (E. Buckler, M. Gore), Signetron Inc. (A. Zakhor)	ARPA-E (DOE)	TERRA-MEPP (Mobile Energy-Crop Phenotyping Platform)	2015-17	\$3,100,000	\$898,374
PI: S. Long Co-PIs: University of Illinois (G. Chowdhary , D. Ort, C. Bernacchi, K. Guan, D. LeBauer), Cornell University (E. Buckler, M. Gore), Signetron Inc. (A. Zakhor)	ARPA-E (DOE)	Plus-Up TERRA-MEPP (Mobile Energy-Crop Phenotyping Platform)	2017-19	\$2,000,000	\$457,439

Principal Investigator (PI), Co-P Investigator (Co-PI)	Funding Agency	Title	Funding Year(s)	Total Funding	Funding Specific to Candidate
PI: S. Long Co-PIs: University of Illinois (G. Chowdhary , D. Ort, C. Bernacchi, L. Ainsworth)	Bill and Melinda Gates Foundation	RIPE (Realizing Increased Photosynthetic Efficiency)	2017-19	\$28,730,247	\$205,838
PI: J. Czarnecki (Mississippi state) Co-PIs: G. Chowdhary (UIUC), Alex Thomasson (TAMU)	USDA	Enhancing Accessibility, Reliability, and validation of actionable information from Unmanned Aerial Vehicle Image Data	2018-20	\$593,397	\$156,830
PI: S. Joshi (NextGen Aeronautics) Co-PIs: G. Chowdhary E. Kapaniya (VT)	NASA	LEARN: Versatile Experimental Autonomy Research Aircraft Technology (VEARAT)	2016	\$250,000	\$97,106
PI: S. Joshi (NextGen Aeronautics) Co-PI: G. Chowdhary	DARPA	IMPROV: Kamikaze Autonomous Swarms	2016-17	\$130,000	\$60,000
PI: S. Karaman (MIT) Co-PI: G. Chowdhary	AFOSR	Dynamic Data-Driven Motion-Planning and Control for Pervasive Situational Awareness Application Systems	2014-17	\$956,674	\$359,951
PI: P. Clark (OSU) Co-PIs: OSU (J. Jacob, G. Chowdhary , T. Lay, J. Pashin, N. Materer)	DOE	Surface and Airborne Monitoring Technology for Detecting Geological Leakage in a COR-Enhanced Oil Recovery Pilot	2013-16	\$894,674	\$250,000
PI: G. Chowdhary	NASA	Developing Adaptive Controllers for Active Wing Shaping on Efficient Lightweight Transport Aircraft	2013	\$2500	\$2500

I. Grant Review Panels

NSF (National Science Foundation): participated in multiple panels including CISE, ENG, and joint NSF-NIFA panels; **Singapore Ministry of Education**; **AFOSR** (Air Force Office of Scientific Research); **National Research Foundation of Korea** (South Korea); **The Nederland Organization for Scientific Research** (Netherlands); **United Arab Emirates University** (UAE).

2. PUBLICATIONS AND CREATIVE WORKS

Candidate name appears in bold font; Names of student and post-doc authors primarily advised by the candidate are underlined; *Names of students* on whose thesis committee the candidate is/was, but was not the primary advisor, appear in italics

A. Doctoral thesis

Concurrent Learning for Convergence in Adaptive Control Without Persistency of Excitation, **Girish Chowdhary**, Georgia Institute of Technology, December 2010

B. Chapters in Books (in print or accepted)

1. **Chowdhary G.**, Muhlegg M., How J. P., Holzapfel F., Concurrent Learning Adaptive Model Predictive Control, pp. 29-47, in Advances in Aerospace Guidance, Navigation, and Control, Springer Berlin Heidelberg, 2013.
2. Kannan S., **Chowdhary G.**, Johnson E., Adaptive Control of Unmanned Aerial Vehicles – Theory and Flight Test Results, Springer handbook of UAVs, January 2014.
3. Chowdhary G., Frazzoli E., **How J.**, Lui H., Nonlinear Flight Control Techniques for Unmanned Aerial Vehicles, Springer handbook of UAVs, January 2014.
4. How J., Frazzoli E., **Chowdhary G.**, Linear Flight Control Techniques for Unmanned Aerial Vehicles, to appear in the Springer handbook of UAVs, January 2014.
5. Ure, N. K., **Chowdhary G.**, How J. P., Vian J., Multi-Agent Planning for Persistent Surveillance, in Planning Under Uncertainty, Chapt. 12, MIT Press, February 2014.
6. Axelrod A., **Chowdhary G.**, The Explore-Exploit Dilemma in Nonstationary Decision Making under Uncertainty, in Handling Uncertainty and Networked Structure in Robot Control, edited by Lucian Bucinou and Levante Tamas, Vol. 42, Chapt. 2, Springer Switzerland, February 2016.
7. Carlone L., Axelrod A., Karman S., **Chowdhary G.**, Aided Optimal Search: Data-Driven Target Pursuit from On-Demand Delayed Binary Observations, Dynamic Data Driven Application Systems, October 2017.
8. Axelrod A., Carlone L., **Chowdhary G.**, Karaman S., Data-driven Prediction of Confidence for EVAR in Time-varying Datasets, Dynamic Data Driven Application Systems, October 2017.
9. Mehendiratta M., Kayacan Erkan, Patel S., Kayacan Erdal and **Chowdhary G.**, Learning-based Fast Nonlinear Model Predictive Control for Custom-made 3D Printed Ground and Aerial Robots, Handbook of Model Predictive Control, Springer, Control Engineering Series, editor Saša V. Raković, William S. Levine, 2018.
10. **Chowdhary G.**, Joshi G., Havens A., Reinforcement Learning and Adaptive Control, In Encyclopedia of Systems and Control, Baillieul J., Samad T. (eds). Springer, London, 2020.

C. Articles in Journals (in print or accepted)

1. Anderson R., **Chowdhary G.**, Johnson E., Comparison of RBF and SHL Neural Network Based Adaptive Control, **Journal of Intelligent and Robotic Systems (JIRS)**, Springer, vol. 54, no. 1-3, pp. 183-199, Sept 2008.
2. **Chowdhary G.**, Jategaonkar R., Parameter Estimation from Flight Data Applying Extended and Unscented Kalman Filter, **Aerospace Science and Technology (AST)**, Vol. 14, no. 2, pp. 106-117, March 2010.
3. **Chowdhary G.**, Srinivasan S., Johnson E., Frequency Domain Method for Real-Time Detection of Oscillations, **AIAA Journal of Aerospace Computing, Information, and Communication** (JACIC now JAIS), Vol. 8, No.2, pp. 42-52, February 2011.
4. **Chowdhary G.**, Johnson E., Theory and Flight Test Validation of a Concurrent Learning Adaptive Controller, **AIAA Journal of Guidance Control and Dynamics (JGCD)**, Vol. 34, No. 2, pp. 592-607, March-April 2011.

5. Kingravi H., **Chowdhary G.**, Vela P., Johnson E., A Reproducing Kernel Hilbert Space Approach for the Online Update of Radial Bases in Neuro-Adaptive Control, **IEEE Transactions on Neural Networks and Learning Systems (TNNLS)**, Vol 23, no. 7, pp 1130-1141, July 2012.
6. **Chowdhary G.**, Sobers D. M., Pravitra C., Christmann C., Wu A., Hashimoto H., Ong C., Kalghatgi R., Johnson E., Self-Contained Ranging Sensor Aided Guidance, Navigation, and Control for Autonomous Indoor Flight, **AIAA Journal of Guidance Control and Dynamics (JGCD)**, Vol. 35, No. 6, pp. 1843-1854, Nov-Dec 2012.
7. **Chowdhary G.**, Yucelen T., Mühlegg M., Johnson E., Concurrent Learning Adaptive Control of Linear Systems with Exponentially Convergent bounds, **Wiley International Journal of Adaptive Control and Signal Processing (IJACSP)**, Vol 27, No. 4, pp 280-301, April 2013.
8. **Chowdhary G.**, Mühlegg M., Johnson E., Exponential Stability Guarantees for Adaptive Systems using Online Recorded Data, **International Journal of Control (IJC)**, Vol 87, No. 8, pp 1583-1603, Dec 2013.
9. **Chowdhary G.**, Johnson E., Chandramohan R., Kimbrell M. S., Calise A., Guidance and Control of Airplanes Under Actuator Failures and Severe Structural Damage, **AIAA Journal of Guidance Control and Dynamics (JGCD)**, vol 36, No. 4, pp. 1093-1104, 2013.
10. **Chowdhary G.**, Sobers M., Salün E., Ottander J., Fully Autonomous Indoor Flight Relying on Five Very Low-Cost Range Sensors, **AIAA Journal of Aerospace Information Systems (JAIS)**, Vol 10, No. 1, pp 21-31, January 2013.
11. **Chowdhary G.**, Johnson E., Magree D., Wu D., Shein A., GPS-Denied Indoor and Outdoor Monocular Vision Aided Navigation and Control of Unmanned Aircraft, **Journal of Field Robotics (JFR)**, Vol 30, No. 3, pp 415-438, March 2013.
12. Wu D., Johnson E., Dallaert F., Kaess M., **Chowdhary G.**, Autonomous Flight in GPS-Denied Environments Using Monocular Vision and Inertial Sensors, **AIAA Journal of Aerospace Information Systems (JAIS)**, Vol 10., No. 4, pp. 172-186, April 2013.
13. Geramifard A., Walsh T. J., Tellex S., **Chowdhary G.**, Roy N., How J. P., A Tutorial on Linear Function Approximators for Dynamic Programming and Reinforcement Learning, **Foundations and Trends in Machine Learning (FTML)**, vol. 6, No. 4, December 2013.
14. Ure N. K., **Chowdhary G.**, Chen Y. F., How J. P., Distributed Learning for Planning Under Uncertainty Problems with Heterogeneous Teams, **Journal of Intelligent and Robotic Systems (JIRS)**, Vol 74, No. 1-2, pp 529-544, April 2014.
15. Ure N. K., **Chowdhary G.**, Toksoz T., How J. P., Vavrina M., Vian J., An Automated Battery Management System to Enable Persistent Missions with Multiple Aerial Vehicles, **IEEE Transactions on Mechatronics**, Vol. 20, No. 1, pp. 275-286, Jan 2014.
16. Grande R., **Chowdhary G.**, How J. P., Experimental Validation of Bayesian Nonparametric Adaptive Control using Gaussian Processes, **AIAA Journal of Aerospace Information Systems (JAIS)**, special issue on applications of reinforcement learning and learning based adaptive control to mechanical and aerospace systems, Vol 11, pp 565-578, July 2014.
17. Mu B., **Chowdhary G.**, How J. P., Efficient Distributed Sensing using Adaptive Censoring Based Inference, **Automatica**, Vol 50, No 6, pp 1590-1602, June 2014.
18. **Chowdhary G.**, Kingravi H., How J. P., Patricio V., Bayesian Nonparametric Adaptive Control using Gaussian Processes, **IEEE Transactions in Neural Networks and Learning Systems (TNNLS)**, Vol 26, No. 3, pp. 537-550, March 2015.
19. **Chowdhary G.**, Liu M., Grande R., Walsh T., How J. P., Carrin L., Off-Policy Reinforcement Learning with Gaussian Processes, **IEEE/CAA Journal of Automatica Sinica** special issue on advances in reinforcement learning and adaptive control, Vol 1, No. 3, pp 227-238, Jan 2015.
20. Ure N. K., **Chowdhary G.**, How J. P., Vian J., Health-Aware Planning Under Uncertainty for Collaborative Heterogeneous Teams of Mobile Agents, **Unmanned Systems**, Vol 3, No. 2, pp 89-107, April 2015.

21. Grande R., Walsh T., Fergusson S., **Chowdhary G.**, and How J. P., Online Regression for Data with Changepoints using Gaussian Processes and Reusable Models, **IEEE Transactions of Neural Networks and Learning Systems (TNNLS)**, vol. 28, no. 9, pp 2115-2128, June 2016.
22. Kamalapurkar R., Reish B., **Chowdhary G.**, Dixon W., Concurrent Learning for Parameter Estimation Using Dynamic State-Derivative Estimators, **IEEE Transactions on Automatic Control (TAC)**, Vol. 62, Issue 7, pp 3594-3601, February 2017.
23. Liu M., **Chowdhary G.**, Bruno D. S., How J. P., Shih-Yuan L., Gaussian Processes for Learning and Control: Tutorial with Examples, **IEEE Control Systems Magazine (CSM)**, vol. 38, no. 5, pp. 53-86, Oct 2018.
24. Kayacan E., Peschel J., **Chowdhary G.**, A Self-Learning Disturbance Observer for Nonlinear Systems, **IFAC Engineering Applications of Artificial Intelligence**, Vol. 62, pp 276-285, April 2017.
25. Kayacan E., Young S., Peschel J., **Chowdhary G.**, High Precision Control of Tracked Field Robots in the Presence of Unknown Traction Coefficients, **Journal of Field Robotics (JFR)**, Vol. 35, no. 7, pp 1050-1062, June 2018.
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27. Shamshiri, Redmond R. S., Weltzien C., Hameed I. A., Yule I. J., Grift T. E., Balasundram S. K., Pitonakova L., Ahmad D., and **Chowdhary G.**, Simulation software and virtual environments for acceleration of agricultural robotics: Features highlights and performance comparison, **International Journal of Agricultural and Biological Engineering**, Vol. 11, no. 4, pp. 15-31, Aug 2018.
28. Shamshiri, Redmond R. S., Weltzien C., Hameed I. A., Yule I. J., Grift T. E., Balasundram S. K., Pitonakova L., Ahmad D., and **Chowdhary G.**, Research and development in agricultural robotics: A perspective of digital farming, **International Journal of Agricultural and Biological Engineering**, Vol. 11, no. 4, pp 1-14, Aug 2018.
29. Kayacan E., **Chowdhary G.**, Tracking Error Learning Control for Precise Mobile Robot Path Tracking in Outdoor Environment, **Journal of Intelligent Robotic Systems (JIRS)**, <https://doi.org/10.1007/s10846-018-0916-3>, Aug 2018.
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32. McAllister W., Osipychev D., **Chowdhary G.**, Davis A., Agbots: Weeding a Field with a Team of Autonomous Robots, **Computers and Electronics in Agriculture (CEA)**, Vol. 163, pp. 104827, May 2019.
33. Jayaraman B., Lu C., Whitman J., **Chowdhary G.**, Spare Feature-Map based Markov Models for Nonlinear Fluid Flows, **Computers and Fluids**, 191, 104252, 2019.
34. Abdollahi A., Chowdhary G., Adaptive-Optimal Control under Time-varying Stochastic Uncertainty Using Past Learning, **International Journal of Adaptive Control and Signal Processing (IJACSP)**, Vol. 33, pp 1803–1824, September 2019.
35. Cai Y., Guan K., Nafziger E., **Chowdhary G.**, Peng B., Jin Z., Wang S., and Wang S., Detecting in-season crop nitrogen stress of corn for field trials using UAV- and CubeSat-based multispectral sensing, **IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing**, vol. 12, no. 12, pp. 5153-5166, Dec. 2019.
36. Gage J., Richard E., Lepak N., Kaczmar N., Soman C., **Chowdhary G.**, Gore M., Buckler E., In-Field Whole-Plant Maize Architecture Characterized by Subcanopy Rovers and Latent Space Phenotyping, the **Plant Phenome Journal**, 2: 1-11 190011, 2019.
37. **Chowdhary G.**, Gazzola M., Krishnan G., Soman C., Lovell S., Soft Robotics as an Enabling Technology for Agroforestry Practice and Research, **Sustainability** special issue on Agroforestry and Ecosystem Regeneration, Nov 2019, 11, 6751.

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39. Kayacan E., Zhongzhong Z., Thompson B., **Chowdhary G.**, High Precision Control and Deep Learning-based Corn Stand Counting Algorithms for Agricultural Robot, **Autonomous Robots**, Vol. 44, pp. 1289–1302, Jun 2020.
40. Zongyao J., Maske H., **Chowdhary G.**, Pagilla P., Task Learning, Intent Prediction, and Adaptive Blended Shared Control with Application to Excavators, **IEEE Transactions on Control Systems Technologies (TCS)**, Vol. 29, Issue 1, pp. 18-28 Jan 2021.
41. Sun, R., Greene M., Le D., Zachary B., **Chowdhary G.**, Dixon W., Lyapunov-Based Real-Time and Iterative Adjustment of Deep Neural Networks, **IEEE Control Systems Letters (L-CSS)**, vol. 6, pp. 193-198, January 2021.
42. Mohamadipanah H., Heydari M., **Chowdhary G.**, Deep Kernel Recursive Least-Squares Algorithm, Springer **Nonlinear Dynamics**, Vol. 104, pp 2515–2530, April 2021.
43. Whitman J., Maske H., Kingravi H., **Chowdhary G.**, Evolving Gaussian Processes and Kernel Observers for Learning and Control in Spatiotemporally Varying Domains, **IEEE Control Systems Magazine (CSM)**, Vol. 41, no. 1, pp. 30-69, Feb 2021, *cover-page article*.
44. Naughton N., Sun J., Tekinalp A., **Chowdhary G.**, Gazzola M., Elastica: A compliant mechanics environment for soft robotic control, **IEEE Robotics and Automation Letters (RA-L)**, vol. 6, no. 2, pp. 3389-3396, April 2021.
45. McAllister W., Whitman J., Varghese J. D., Davis A., **Chowdhary G.**, Agbots 3.0: Adaptive Weed Growth Prediction for Mechanical Weeding Agbots, **IEEE Transactions on Robotics (TRO)**, vol. 38, no. 1, pp. 556-568, Feb. 2022.
46. Sun, R., Greene M., Le D., Zachary B., **Chowdhary G.**, Dixon W., Lyapunov-Based Real-Time and Iterative Adjustment of Deep Neural Networks, **IEEE Control Systems Letters (L-CSS)**, Vol 6, pp 193-198, June 2021.
47. Tianchen J., Sivakumar A. N., **Chowdhary G.**, Driggs-Campbell K., Proactive Anomaly Detection for Robot Navigation with Multi-Sensor Fusion, **Robotics and Automation Letters (R-AL)**, vol. 7, no. 2, pp. 4975-4982, April 2022.
48. Mishra P., **Chowdhary G.**, Mehta G., Minimum Variance Constrained Estimator, **Automatica**, Vol. 137, March 2022
49. Choi J. W., Borkar A., Singer A., **Chowdhary G.**, Broadband Acoustic Communication Aided Underwater Inertial Navigation, **Robotics and Automation Letters (R-AL)** joint with **ICRA**), accepted January 2022
50. Baquero A., Higuti V. A., Gasparino M. V., Sivakumar A. N., Becker M., **Chowdhary G.** Multi-Sensor Fusion based Robust Row Following for Compact Agricultural Robots, **Journal of Field Robotics (JFR)**, accepted February 2022.
51. Kamtikar S., Marri S., Walt B., Uppalapati K. N., Krishnan G., **Chowdhary G.**, Visual Servoing for Pose Control of Soft Continuum Arm in a Structured Environment, Jointly published in **Robotics and Automation Letters (R-AL)** joint with IEEE 5th International Conference on Soft Robotics (**RoboSoft**)), Edinburgh, Scotland, UK, April 2022.
52. Khanna M., Atallah S., Saurajyoti K., Sharma B., Wu L., Yu C., **Chowdhary G.**, Soman C., Guan K., Digital Transformation for a Sustainable Agriculture in the US: Opportunities and Challenges, **Agricultural Economics**, Vol. 53, No. 6, pp 924-937, July 2022
53. Gasparino M., Narenthiran A., Liu Y., Velasquez A., Higuti A., Rogers J. III, Tran H. T., **Chowdhary G.**, WayFAST: Traversability Predictive Navigation for Field Robots, **Robotics and Automation Letters (R-AL)** joint with **IROS** 2022
54. Davidson C., Jagannath V., Narenthiran A. S., Czarnecki J. P., Chowdhary G., NDVI/NDRE Prediction from Standard RGB Aerial Imagery Using Deep Learning, **Computers and Electronics in Agriculture (CEA)**, Vol 203, 107396, December 2022.
55. Zegers F., Sun R., **Chowdhary G.**, Dixon W. Distributed State Estimation with Deep Neural Networks for Uncertain Nonlinear Systems under Event-Triggered Communication, **IEEE Transactions on Automatic Control (TAC)**, vol. 68, no. 5, pp. 3107-3114 May 2023

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57. Wu, J., Ackerman, A., Gaire, R., **Chowdhary, G.**, & Rutkoski, J. A neural network for phenotyping *Fusarium*-damaged kernels (FDKs) in wheat and its impact on genomic selection accuracy. *The Plant Phenome Journal*, 6, 1– 14, March 2023.
58. Valenzuela Jose Curan, Gasprino Mateus, Uppalapati Naveen, Narenthiran Arun, Wasserman Justin, Ali Huzaifa, Adve Sarita, **Chowdhary Girish**, Under-Canopy Dataset for Advancing Simultaneous Localization and Mapping in Agricultural Robotics, **International Journal of Robotics Research (IJRR)**, Vol. 43, no. 46, Nov 2023.
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61. Mishra Prabhat, Gasparino Mateus, **Chowdhary Girish**, Deep Model Predictive Control with Stability Guarantees, **IEEE Transactions on Automatic Control (TAC)**, accepted October 2024
62. Akcal Ugur, Raikov Ivan, Gribkova Ekaterina, Choudhuri Anwesa, Kim Seung Hyun, Gazzola Mattia, Gillette Rhanor, Soltesz Ivan, **Chowdhary Girish**, Localizing convolutional spikin neural network for fast visual place recognition, *Frontiers in Neurorobotics*, accepted December 2024.

D. Peer-Reviewed Conference Papers and Presentations (including Top-Tier conferences)

1. Danapalasingam A. K., Cour-Harbo A., **Chowdhary G.**, Bisgaard A., A Robust Stabilization using State Feedback with Feedforward, American Control Conference (ACC), MD, USA 2010.
2. **Chowdhary G.**, Johnson E., Recursively Updated Least Squares Based Modification Term for Adaptive Control, American Control Conference (ACC), MD, USA 2010.
3. **Chowdhary G.**, Johnson E., Least Squares Based Modification for Adaptive Control, IEEE Conference on Decision and Control (CDC), GA, USA 2010.
4. **Chowdhary G.**, Johnson E., Concurrent Learning for Convergence in Adaptive Control without Persistency of Excitation, IEEE Conference on Decision and Control (CDC), GA, USA 2010.
5. **Chowdhary G.**, Johnson E., Adaptive Flight Control with Guaranteed Convergence, CEAS EuroGNC, Munich, Germany 2011.
6. **Chowdhary G.**, Johnson E., A Singular Value Maximizing Data Recording Algorithm for Concurrent Learning, American Control Conference (ACC), CA, USA 2011, winner of best presentation in session award.
7. **Chowdhary G.**, Egerstedt M., Johnson E., Network Discovery: An Estimation Based Approach, American Control Conference (ACC), CA, USA 2011, winner of best presentation in session award.
8. Kingravi H., **Chowdhary G.**, Vela P., Johnson E., A Reproducing Kernel Hilbert Space Approach for the Online Update of Radial Bases in Neuro-Adaptive Control, IEEE Conference on Decision and Control (CDC), FL 2011.
9. Pravitra C., **Chowdhary G.**, Johnson E., A Compact Exploration Strategy for Indoor Flight Vehicle, IEEE Conference on Decision and Control (CDC), FL 2011.
10. Üre N. K., **Chowdhary G.**, Redding J., Toskoz T., How J., Vavrina M., Vian J., Experimental Demonstration of Efficient Multi-Agent Learning and Planning for Persistent

- Missions in Uncertain Environments, AIAA Guidance Navigation and Control Conference (GNC), MN 2012, *winner of best paper* of **AIAA GNC** 2012 out of over 600 papers.
11. Üre N. K., Geramifard A., **Chowdhary G.**, How J., Adaptive Planning for Markov Decision Processes with Uncertain Transition Models via Incremental Feature Dependency Discovery, European Conference on Machine Learning (**ECML**), Bristol, UK 2012. *Acceptance rate* < 25%.
 12. Mu B., **Chowdhary G.**, How J. P., Efficient Distributed Sensing using Adaptive Censoring Based Inference, IEEE American Control Conference (**ACC**), DC 2013.
 13. De La Torre G., **Chowdhary G.**, Johnson E. N., Concurrent Learning Adaptive Control of Linear Switched Systems, IEEE American Control Conference (**ACC**), DC 2013.
 14. **Chowdhary G.**, Kingravi H., How J. P., Vela P. A., Nonparametric Adaptive Control of Time-Varying Systems using Gaussian Processes, IEEE American Control Conference (**ACC**), DC 2013.
 15. **Chowdhary G.**, Wu T., Cutler M., How J. P., Rapid Transfer of Controllers Between UAVs using Learning Based Adaptive Control, IEEE International Conference on Robotics and Automation (**ICRA**), Germany 2013.
 16. **Chowdhary G.**, Muhlegg M., How J. P., Holzapfel F., Concurrent Learning Adaptive Model Predictive Control, European Guidance, Navigation, and Control Conference (**E-GNC**), Netherlands 2013.
 17. Üre N. K., **Chowdhary G.**, How J. P., Vavrina M., Vian J., Health Aware Planning Under Uncertainty for UAV Missions with Heterogeneous Teams, IEEE European Control Conference (**ECC**), Switzerland 2013.
 18. Üre N. K., **Chowdhary G.**, Chen Y. F., How J. P., Vian J., Decentralized Learning and Planning for Multiagent Missions in Presence of Actuator Failures, International Conference on Unmanned Aircraft Systems (**ICUAS**), GA, May 2013.
 19. Amato C., **Chowdhary G.**, Geramifard A., Üre N. K., Kochenderfer M. J., Decentralized Control of Partially Observable Markov Decisions Processes, IEEE Conference on Decisions and Control (**CDC**), Firenze, Italy, December 2013.
 20. Grande R., **Chowdhary G.**, How J. P., Nonparametric Adaptive Control using Gaussian Processes with Online Hyperparameter Estimation, IEEE Conference on Decisions and Control (**CDC**), Firenze, Italy, December 2013.
 21. **Chowdhary G.**, Muhlegg M., How J. P., Holzapfel F., A Concurrent Learning Adaptive-Optimal Architecture for Nonlinear Systems, IEEE Conference on Decisions and Control (**CDC**), Firenze, Italy, December 2013.
 22. **Chowdhary G.**, Kingravi H., How J. P., Patricio V., A Bayesian Nonparametric Approach to Adaptive Control using Gaussian Processes, IEEE Conference on Decisions and Control (**CDC**), Firenze, Italy, December 2013.
 23. Üre N. K., Chen Y. F., **Chowdhary G.**, How J. P., Vian J., Planning for Large-Scale Multiagent Problems via Hierarchical Decomposition with Applications to UAV Health Management, American Control Conference (**ACC**), OR, June 2014.
 24. Allamaraju R., Kingravi H., Axelrod A., **Chowdhary G.**, Grande R., How J. P., Crick C., Sheng W., Human Aware Path Planning in Urban Environments with Nonstationary MDPs, IEEE International Conference on Robotics and Automation (**ICRA**), Hong-Kong China, May 2014.
 25. Abdollahi A., Allamaraju R., **Chowdhary G.**, Adaptive Optimal Control of Nonstationary Dynamical Systems, European Guidance Navigation and Control conference (**E-GNC**), Toulouse, France, 2015.
 26. Reish, B., **Chowdhary G.**, Concurrent Learning Adaptive Control for Systems with Unknown Sign of Control Effectiveness, IEEE Conference on Decision and Control (**CDC**), CA, Dec 2015.
 27. Peterson, J. D., Yucelen T., Kannan K., **Chowdhary G.**, Exploitation of Heterogeneity in Distributed Sensing: An Active-Passive Networked Multiagent Systems Approach, American Control Conference (**ACC**), IL 2015.
 28. Quindlen J., **Chowdhary G.**, How J., Hybrid Model Reference Adaptive Control for Unmatched Uncertainties, American Control Conference (**ACC**), IL 2015.

29. Axelrod A., Kingravi H., **Chowdhary G.**, Gaussian Process based Subsumption of Parasitic Control, American Control Conference (ACC), IL 2015.
30. Axelrod A., **Chowdhary G.**, Karaman S., Exploitation by informed exploration between isolated operatives for information theoretic data harvesting, IEEE Conference on decision and control (CDC), Osaka, Japan, Dec 2015.
31. Kingravi H., Maske H., Chowdhary G., Kernel Controllers: A Systems Theoretic Approach for Modeling and Control of Spatiotemporally Evolving Processes, IEEE Conference on decision and control (CDC), Osaka, Japan, Dec 2015.
32. Quindlen J., Topcu U., How J. P., **Chowdhary G.**, Region of Convergence Estimation for Learning based Adaptive Controllers, American Control Conference (ACC), Boston MA, May 2015.
33. Muehlegg M., **Chowdhary G.**, Holzapfel F., State Monitoring of Systems Augmented by Model Reference Adaptive Control using Analytic Time-Series Forecasting, 24th Mediterranean Conference on Control and Automation, Athens Greece, June 2016.
34. Maske H., **Chowdhary G.**, Pagilla P., Intent Aware Shared Control in Off-Nominal Situations, Conference on Decision and Controls (CDC), Las Vegas, NV, Dec 2016.
35. Axelrod A., Carlone L., **Chowdhary G.**, Karaman S., Data-driven Prediction of EVAR with Confidence in Time-varying Datasets, Conference on Decision and Controls (CDC), Las Vegas, NV, Dec 2016.
36. Kingravi H., Maske H., **Chowdhary G.**, Kernel Observers: Systems-Theoretic Modeling and Inference of Spatiotemporally Varying Processes, Neural Information Processing Systems (NeurIPS), Barcelona, Spain Dec 2016, *acceptance rate 22.5%*.
37. Osipychiev D., Duy T., Sheng W., **Chowdhary G.**, Human Intention based Collision Avoidance for Autonomous Cars, American Control Conference, Seattle WA, May 2017.
38. Seiferth D., **Chowdhary G.**, Muehlegg M., Holzapfel F., Online Gaussian Process Regression with Non-Gaussian Likelihood, American Control Conference (ACC), Seattle WA, May 2017.
39. Allamaraju R., **Chowdhary G.**, Communication Efficient Decentralized Gaussian Process Fusion for Multi-UAS Path Planning, American Control Conference (ACC), Seattle WA, May 2017.
40. Allain M., Konduri S., Maske H., Pagilla P., **Chowdhary G.**, Blended Shared Control of a Hydraulic Excavator, 20th International Federation of Automatic Control (IFAC) World Congress, France, July 2017.
41. Whitman J., **Chowdhary G.**, Learning Dynamics Across Similar Spatiotemporally Evolving Systems, Conference on Robot Learning (CORL), San Jose, CA, Nov 2017, *accepted for long-talk, long-talk acceptance rate 10%*.
42. Maske H., Kingravi H., **Chowdhary G.**, Sensor Selection via Observability Analysis in Feature Space, American Control Conference (ACC), WI, 2018.
43. Quindlen J., Topcu U., **Chowdhary G.**, How J. P., Closed-Loop Statistical Verification of Stochastic Nonlinear Systems Subject to Parametric Uncertainties, American Control Conference (ACC), WI, 2018.
44. Quindlen J., Topcu U., **Chowdhary G.**, How J. P., Active Sampling for Closed-Loop Statistical Verification of Uncertain Nonlinear Systems, American Control Conference (ACC), WI, 2018.
45. Maske H., **Chowdhary G.**, Kieson E., Abramson C., Learning Instructional Policy to Teach Construction Task, International Conference on Robotics and Automation (ICRA), Brisbane, Australia, June 2018.
46. Joshi G., **Chowdhary G.**, Cross-Domain Transfer in Reinforcement Learning using Target Apprentice, International Conference on Robotics and Automation (ICRA), Brisbane, Australia, June 2018.
47. Kayacan E., Zhongzhong Z., **Chowdhary G.**, Embedded High Precision Control and Corn Stand Counting Algorithms for an Ultra-Compact 3D Printed Field Robot, Robotics Science and Systems (RSS), Pittsburgh, PA, June 2018, *acceptance rate 31%. Winner of best systems paper award.*

48. McAllistar W., Osipychhev D., **Chowdhary G.**, Davis A., Multi-Agent Planning for Coordinated Robotic Weed Killing, IEEE/RSJ International Conference on Intelligent Robots and Systems (**IROS**), Madrid, Spain, Sept 2018.
49. Zongyao J., Pagilla P., Maske H., **Chowdhary G.**, Task Learning, Intent Prediction, and Blended Shared Control of a Hydraulic Excavator, IEEE Conference on Decision and Control (**CDC**), Miami, FL, Dec 2018.
50. Maske H., **Chowdhary G.**, Likelihood Rate based Estimation of Nonstationary Markov Models, IEEE Conference on Decision and Control (**CDC**), Miami, FL, Dec 2018.
51. Joshi G., **Chowdhary G.**, Adaptive Control using Gaussian-Process with Model Reference Generative Network, IEEE Conference on Decision and Control (**CDC**), Miami, FL, Dec 2018.
52. Satheeshbabu S., Uppalapati N. K., **Chowdhary G.**, Krishnan G. Open loop position control of soft continuum arms using deep reinforcement learning, , International Conference on Robotics and Automation (**ICRA**), Montreal, CA, May 2019.
53. Madhusudhan. M., **Chowdhary G.**, Deep SRGM, Sequence Classification and Ranking in Indian Classical Music via Deep Learning, International Society of Music Information Retrieval (**ISMIR**), Delft, Netherlands, Sept 2019.
54. Joshi G., **Chowdhary G.**, Deep Model Reference Adaptive Control, IEEE Conference on Decision and Control (**CDC**), Nice FR, Dec 2019.
55. Van Stralen N., Seung Huyn K., Tran H., **Chowdhary G.**, Evaluating Adaptive Performance of Hierarchical Deep Reinforcement Learning, IEEE International Conference on Robotics and Automation (**ICRA**), Paris Fr, May 2020.
56. Uppalapati N., Havens A., Walt B., Chowdhary G., Krishnan G., A Berry Picking Robot With A Hybrid Soft-Rigid Arm: Design and Task Space Control, Robotics Science and Systems (**RSS**), Oregon State University (held online due to COVID-19), OR, July 2020. *Average acceptance rate 28.6%.*
57. McAllistar W., Whitman J., Axelrod A., Varghese J., Davis A., Chowdhary G., Agbots 2.0: Weeding Denser Fields with Fewer Robots, Robotics Science and Systems (**RSS**), Oregon State University (held online due to COVID-19), OR, July 2020. *Average acceptance rate 28.6%.*
58. Joshi Girish, Virdi Jasvir, **Chowdhary G.**, Asynchronous Deep Model Reference Adaptive Control, Conference on Robot Learning (**CORL**), Massachusetts Institute of Technology (held online due to COVID-19), MA, Nov 2020. *Average acceptance rate 34%.*
59. Ji Tianchen, Vuppala Sri, **Chowdhary G.**, Driggs-Campbell K., Multi-Modal Anomaly Detection for Unstructured and Uncertain Environments, Conference on Robot Learning (**CORL**), Massachusetts Institute of Technology (held online due to COVID-19), MA, Nov 2020. *Average acceptance rate 34%.*
60. Borkar Aseem V., **Chowdhary G.**, Multi-Agent Aerial Monitoring of Moving Convoys using Elliptical Orbits, International Conference on Robotics and Automation (**ICRA**), XiAn China and online, June 2021.
61. Havens Aaron, **Chowdhary G.**, Forced Variational Integrator Networks for Prediction and Control of Mechanical Systems, Learning for Decision and Control (**L4DC**), ETH Zurich, Switzerland, June 2021.
62. Narenthiran A., Modi S., Valverde Mateus, Baquero Andres, Ellis Che, **Chowdhary G.**, Gupta S., Learned Visual Navigation for Under-Canopy Agricultural Robots, Robotics Science and Systems (**RSS**), July 2021
63. Cui Hang, Wu Junzhe, Zhang Jiaming, **Chowdhary G.**, Norris W., 3D Detection and Tracking for On-road Vehicles with a Monovision Camera and Dual Low-cost 4D mmWave Radars, IEEE International Intelligent Transportation Systems Conference (**ITSC**), 2021
64. Choudhuri A., **Chowdhary G.**, Schwing A., Structured Prediction on Top-K Assignments for Multi-Object Tracking and Segmentation, International Conference on Computer Vision (**ICCV**), virtual due to COVID-19, 2021, acceptance rate 25.9%
65. Joshi G., **Chowdhary G.**, Stochastic Deep Model Reference Adaptive Control, IEEE Conference on Decision and Control (**CDC**), Austin TX, December 2021

66. Kim S. H., Van Stralen N., **Chowdhary G.**, Tran H. , Disentangling Successor Features for Coordination in Multi-agent Reinforcement Learning, International Conference on Autonomous Agents and Multi-Agent Systems (**AAMAS-2022**), accepted as full paper, held virtual due to COVID-19, 2022, acceptance rate 26% for full papers.
67. Tianchen J., Sivakumar A. N., **Chowdhary G.**, Driggs-Campbell K., Proactive Anomaly Detection for Robot Navigation with Multi-Sensor Fusion, Jointly published in Robotics and Automation Letters, and International Conference on Robotics and Automation (**ICRA**), PA, May 2022.
68. Choi J. W., Borkar A., Singer A., **Chowdhary G.**, Broadband Acoustic Communication Aided Underwater Inertial Navigation, Jointly published in Robotics and Automation Letters, and International Conference on Robotics and Automation (**ICRA**), PA, May 2022.
69. Kamtikar S., Marri S., Walt B., Uppalapati K. N., Krishnan G., **Chowdhary G.**, Visual Servoing for Pose Control of Soft Continuum Arm in a Structured Environment, Jointly published in Robotics and Automation Letters, and IEEE 5th International Conference on Soft Robotics (**RoboSoft**), Edinburgh, Scotland, UK, April 2022.
70. Gasparino M., Narenthiran A., Liu Y., Velasquez A., Higuti A., Rogers J. III, Tran H. T., **Chowdhary G.**, WayFAST: Traversability Predictive Navigation for Field Robots, R-AL joint with **IROS** 2022
71. Wasserman J., Yadav K., **Chowdhary G.**, Gupta Abhinav, Jain Unnat, Last Mile Embodied Visual Navigation, Conference on Robot Learning (**CORL**), Auckland NZ, Dec. 2022
72. Mateus Valverde Gasparino, Vitor Akihiro Hisano Higuti, Arun Narenthiran Sivakumar, Andres Eduardo Baquero Velasquez, Marcelo Becker, **Chowdhary G.**, CropNav: A Framework for Autonomous Navigation in Real Farms, in IEEE International Conference on Robotics and Automation (**ICRA**), London, UK, June 2023
73. Choudhari A., **Chowdhary G.**, Schwing A., Context-Aware Relative Object Queries to Unify Video Instance and Panoptic Segmentation, in IEEE Conference on Computer Vision and Pattern Recognition (**CVPR**), Vancouver, CA, June 2023
74. Yifan Zhao, Hashim Sharif, Peter Pao-Huang, Vatsin Shah, Arun Narenthiran Sivakumar, Mateus Valverde Gasparino, Mahmoud A., Zhao N., Adve S., **Girish Chowdhary**, Misailovic S., Adve V.. 2023. ApproxCaliper: A Programmable Framework for Application-aware Neural Network Optimization, Sixth Conference on Machine Learning and Systems (**MLSys**), Miami, Florida, June 2023.
75. Wang Q., Li M., Chan Pong Hou, Huang L., Hockenmaier J., Ji Heng, **Chowdhary G.**, Multimedia Generative Script Learning for Task Planning, 61st Annual Meeting of the Association of Computational Linguistics (**ACL**) 2023, Toronto Canada, July 2023.
76. Gasparino M., Mishra P., **Chowdhary G.**, Learning Based Model Predictive Control with Deep Neural Network, IEEE Conference on Decision and Control (**CDC**), Singapore, 2023
77. Gasparino M., Sivakumar A., **Chowdhary G.**, WayFASTER: a Self-Supervised Traversability Prediction for Increased Navigation Awareness, International Conference on Robotics and Automation (**ICRA**), Yokohoma, Japan, May 2024.
78. Wasserman Justin, **Chowdhary Girish**, Gupta Abhinav, Jain Unnat, Exploitation-Guided Exploration for Semantic Embodied Navigation, International Conference on Robotics and Automation (**ICRA**), Yokohoma, Japan, May 2024.
79. Arun Narenthiran Sivakumar, Mateus Valverde Gasparino, Michael McGuire, Akihiro Higuti, Ugur Ackal, Girish Chowdhary, Demonstrating CropFollow++: Robust Under-Canopy Navigation with Keypoints, Robotics Science and Systems (**RSS**), acceptance rate 29%, Delft, Netherlands, July 2024, **Finalist for Best Demonstration Track Paper Award**.
80. Jiarui Sun, **Girish Chowdhary**, CoMusion: Towards Consistent Stochastic Human Motion Prediction via Motion Diffusion, European Conference on Computer Vision (**ECCV**), acceptance rate 27.9, Milan, Italy, September 2024.
81. Jiarui Sun, Yujie Fan, Chin-Chia Michael Yeh, Wei Zhang and **Girish Chowdhary**, Revealing the Power of Masked Autoencoders in Traffic Forecasting, 33rd ACM International Conference on Information and Knowledge Management (**CIKM**), acceptance rate 27%, Boise, Idaho, October 2024.

82. Anwesa Choudhuri, **Chowdhary Girish**, Schwing Alex, OW-VISCapTor: Abstractors for Open-World Video Instance Segmentation and Captioning, Neural Information Processing Systems (**NeurIPS**), Vancouver, CA, December 2024.
 83. Wasserman Justin, Agarwal Ananye, Jangir Rishabh, **Chowdhary Girish**, Pathak Deepak, Gupta Abhinav, Legolas: Deep Leg-Inertial Odometry, Conference on Robot Learning (**CORL**), Munich, Germany, November 2024, acceptance rate 39.49%.
 84. Cuaran Jose, Ahluwalia Kulbir, Koe Kendall, Uppalapati Naveen Kumar, **Girish Chowdhary**, Active Semantic Mapping with Mobile Manipulators in Horticultural Environments, IEEE International Conference on Robotics and Automation (**ICRA**), Atlanta GA, May 2025
- E. Patents
1. **Chowdhary G.**, Johnson E., Oh S. M., USPTO# US 8489528 B2, Systems and methods for training neural networks based on concurrent use of current and recorded data, Patent assigned to Georgia Institute of Technology, Feb 2013.
 2. **Chowdhary G.**, Choudhuri A., Zhang Z., Soman C., Kayacan E., Thompson B., OTM Ref: 2017-030-04, PCT/US18/47947, "Apparatus and Method for Agricultural Data Collection and Agricultural Operations" filed Aug 24, 2018.
 3. **Chowdhary G.**, Soman C., OTM Ref: 2016-199-02, PCT/US2018/014695 "Adaptive Cyber-Physical System for Efficient Monitoring of Unstructured Environments" filed Jan 22, 2018.
 4. Choudhuri A., **Chowdhary G.**, Kayacan E., Soman C., Tompson B., Zhonzhon Z., Apparatus and method for agricultural data collection and agricultural operations, AU2018320964B2, under review
 5. **Chowdhary G.**, Soman C., Liu P., McGuire M., Hansen M., Agricultural Analysis Robotic Systems and Methods Thereof, WO2022208219A1, awaiting issuance
 6. Chowdhary G., Joshi G., Virdi J., Deep Model Reference Adaptive Controller, 17/354,912, priority date June 22 2021, allowed August 7 2024
- F. Papres in regular conferences and conferences requiring only abstract submissions
These conference proceedings require peer review of abstracts or extended abstracts
1. **Chowdhary G.**, Jategaonkar R., Aerodynamic Parameter Estimation from Flight Data applying Extended and Unscented Kalman Filter, AIAA Atmospheric Flight Mechanics (AFM), CO, USA 2006.
 2. **Chowdhary G.**, Lorenz S., Control of VTOL UAV via Online Parameter Identification, AIAA Guidance Navigation and Control Conference (GNC), CA, USA 2005.
 3. **Chowdhary G.**, Johnson E., Adaptive Neural Network Flight Control using both Current and Stored data, Proc. of AIAA Guidance Navigation and Control Conference (GNC), NC, USA 2007.
 4. Kutay A., **Chowdhary G.**, Calise A., Johnson E., A Comparison of Two Novel Direct Adaptive Control Methods under Actuator Failure Accommodation, Proc. of AIAA Guidance Navigation and Control Conference (GNC), HI, USA 2008.
 5. **Chowdhary G.**, Johnson E., Theory and Flight Test Validation of Long Term Learning Adaptive Controller, Proc. of AIAA Guidance Navigation and Control Conference (GNC), HI, USA 2008.
 6. **Chowdhary G.**, Gadre R., Komerath N., Policy Issues for Retail Beamed Power Transmission, Science and Innovation Policy, GA, USA 2009.
 7. **Chowdhary G.**, Sobers M., Christmann C. H., Kimbrell S. M., Johnson E., Georgia Tech Aerial Robotics Team: 2009 International Aerial Robotics Competition Entry, First Symposium on Indoor Flight Issues, University of Puerto Rico Mayagüez, PR, USA 2009, winner of best paper award.
 8. Sobers M., **Chowdhary G.**, Johnson E., Indoor Navigation for Unmanned Aerial Vehicles, Proc. of AIAA Guidance Navigation and Control Conference (GNC), IL, USA 2009.
 9. Rooz N., Johnson E., **Chowdhary G.**, and others, Experience with Highly Automated Unmanned Aircraft Performing Complex Missions, Proc. of AIAA Guidance Navigation and Control Conference (GNC), IL, USA 2009.

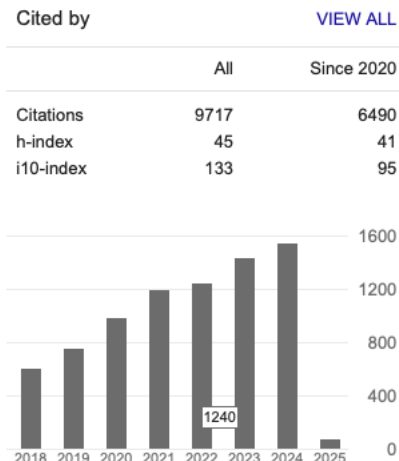
10. Kimbrell S., Johnson E., **Chowdhary G.**, Calise A., Chandramohan R., A Process to Obtain Robustness Metrics for Adaptive Flight Controllers, AIAA Guidance Navigation and Control Conference (GNC), IL, USA 2009.
11. Debusk W., **Chowdhary G.**, Johnson E., Real-Time System Identification of a Small Multi-Engine Aircraft, AIAA Guidance Navigation and Control Conference (GNC), IL, USA 2009.
12. **Chowdhary G.**, Johnson E., Flight Validation of a Long Term Learning Adaptive Controller, Proc. of AIAA Guidance Navigation and Control Conference (GNC), IL, USA 2009.
13. **Chowdhary G.**, Salaün E., Ottander J., Johnson E., Low Cost Guidance Navigation and Control Solution for Miniature UAV in GPS Denied Environment, First Symposium on Indoor Flight Issues, University of Puerto Rico Mayagüez, PR, USA 2009.
14. **Chowdhary G.**, Srinivasan S., Johnson E., Frequency Domain Method for Real-Time Detection of Oscillations, AIAA Infotech@Aerospace, GA, USA 2010, finalist for best student paper award.
15. **Chowdhary G.**, Komerath N., Innovations Required for Retail Beamed Power Transmission Over Short Range, Proc. of IMETI, FL, USA 2010.
16. **Chowdhary G.**, Sobers M. D., Chintasiddhi P., Hiroyuki H., Kalghatgi R., Ong C., Christmann C. H., Johnson E., Georgia Tech Team Entry for the 2010 AUVERSI International Aerial Robotics Competition, Second Symposium on Indoor Flight Issues, University of Puerto Rico Mayagüez, PR, 2010.
17. Chandramohan R., Yucelen T., Calise A., **Chowdhary G.**, Johnson E., Experimental Evaluation of Derivative Free Model Reference Adaptive Control, AIAA Guidance Navigation and Control Conference (GNC), Toronto, Canada 2010.
18. Chandramohan R., Yucelen T., Calise A., **Chowdhary G.**, Johnson E., Flight Test Results for Kalman Filter Modification in Adaptive Control, AIAA Guidance Navigation and Control Conference (GNC), Toronto, Canada 2010.
19. **Chowdhary G.**, Sobers M., Salün E., Ottander J., Johnson E., Design, Development, and Testing of a Low Cost, Fully Autonomous Indoor Unmanned Aerial System, AIAA Guidance Navigation and Control Conference (GNC), Toronto, Canada 2010.
20. **Chowdhary G.**, Johnson E., Concurrent Learning for Improved Parameter Convergence in Adaptive Flight Control, AIAA Guidance Navigation and Control Conference (GNC), Toronto, Canada 2010.
21. Chowdhary G., Johnson E., Kimbrell S., Chandramohan R., Calise A., Flight Test Results of Adaptive Controllers in the Presence of Significant Aircraft Faults, AIAA Guidance Navigation and Control Conference (GNC), Toronto, Canada 2010. Invited Paper.
22. Komerath N., **Chowdhary G.**, Retail Beamed Power for Micro Renewable Energy Architectures: A Survey, Proc. of ISED, Bhubaneswar, India 2010.
23. Johnson E., **Chowdhary G.**, Chandramohan R., Calise A., UAV Flight Control using Flow Control Actuators, AIAA Guidance Navigation and Control Conference (GNC), OR 2011.
24. **Chowdhary G.**, Sobers D. M., Pravitra C., Christmann C., Wu A., Hashimoto H., Ong C., Kalghatgi R., Johnson E., Integrated Guidance Navigation and Control for a Fully Autonomous Indoor UAS, AIAA Guidance Navigation and Control Conference (GNC), OR 2011.
25. **Chowdhary G.**, Johnson E., Lyapunov-based Integration of a Data Recording Algorithm in Adaptive Control, AIAA Guidance Navigation and Control Conference (GNC), OR 2011.
26. Mühlegg M., **Chowdhary G.**, Johnson E. N., Concurrent Learning Adaptive Control of Linear Systems with Noisy Measurements, AIAA Guidance Navigation and Control Conference (GNC) MN, 2012.
27. Campbell T., Ponda S., **Chowdhary G.**, How J., Planning under Uncertainty using Nonparametric Bayesian Models, AIAA Guidance Navigation and Control Conference (GNC), MN 2012.

28. **Chowdhary G.**, Mühlegg M., Üre N. K., Johnson E. N., How J., Experimental Results of Concurrent Learning Adaptive Controllers, AIAA Guidance Navigation and Control Conference (GNC) MN, 2012, Invited Paper.
29. Liu M., **Chowdhary G.**, Carrin L., How J. P., Transfer Learning for Reinforcement Learning with Dependent Dirichlet Process and Gaussian Process, workshop on Bayesian Nonparametric Modeling in Planning and Learning, NIPS Conference, Lake Tahoe NV 2012.
30. **Chowdhary G.**, Kingravi H., Grande R., How J. P., Vela P., Model Reference Adaptive Control using Gaussian Processes, RLDM 2013, Princeton NJ.
31. **Chowdhary G.**, Liu M., Grande R., Walsh T., How J. P., Off-Policy Reinforcement Learning with Gaussian Processes, Reinforcement Learning and Decision Making workshop 2013, Princeton, NJ.
32. Allamaraju R., Kingravi H., Axelrod A., **Chowdhary G.**, Grande R., How J. P., Crick C., Sheng W., Human Aware Path Planning in Urban Environments with Nonstationary MDPs, NIPS Advances in Machine Learning for Sensorimotor Control workshop, Lake Tahoe NV 2013.
33. **Chowdhary G.**, Üre N. K., How J., Kingravi H., Model Reference Adaptive Control using Nonparametric Adaptive Elements, AIAA Guidance Navigation and Control Conference (GNC), MN 2012, Invited Paper.
34. Scheper K., **Chowdhary G.**, Johnson E., Aerodynamic Parameter Identification of a Fixed Wing UAV, AIAA Atmospheric Flight Mechanics Conference (AFM), DC 2013.
35. Muhlegg M., **Chowdhary G.**, Holzapfel F., How J., Adaptive-Optimal Control of Constrained Nonlinear Uncertain Dynamical Systems using Concurrent Learning Model Predictive Control, AIAA Guidance, Navigation, and Control Conference (GNC), MA 2013.
36. Modares H., Lewis F., Naghibi-Sistani M., **Chowdhary G.**, Yucelen T., Adaptive Optimal Control of Partially Constrained-input Systems using Policy Iteration and Experience Replay, AIAA Guidance, Navigation, and Control Conference (GNC), MA 2013.
37. Mu B., **Chowdhary G.**, How J. P., Value-of-Information Aware Active Task Assignment, SPIE Conference on Radar Systems, NJ 2013.
38. Mu B., **Chowdhary G.**, How J. P., Value-of-Information Aware Active Task Assignment, AIAA Guidance, Navigation, and Control Conference (GNC), MA 2013.
39. Muhlegg M., **Chowdhary G.**, Holzapfel, F., Optimizing Reference Commands for Concurrent Learning Adaptive-Optimal Control of Uncertain Dynamical Systems, AIAA Guidance, Navigation, and Control Conference (GNC), MA 2013.
40. **Chowdhary G.**, Üre N. K., How J., Vian J., Concurrent Learning Adaptive Control in Presence of Uncertain Control Allocation Matrix, AIAA Guidance, Navigation, and Control Conference (GNC), MA 2013.
41. **Chowdhary G.**, Kingravi H., How J., Vela P. Nonparametric Adaptive Control using Gaussian Processes, AIAA Guidance, Navigation, and Control Conference (GNC), MA 2013.
42. Osipych D., Tran D., Sheng W., **Chowdhary G.**, Proactive MDP based Collision Avoidance Algorithms for Autonomous Car, NIPS From Bad Models to Good Policies workshop, Montreal, CA 2014
43. Maske H., Matthews M., Axelrod A., **Chowdhary G.**, Crick C., Pagilla P., Collaborative Goal and Policy Learning from Human Operators of Construction Co-Robots, Neural Information Processing Systems (NIPS) Autonomous Learning Robots workshop, Montreal, CA 2014, winner of student travel award.
44. Quindlen J., **Chowdhary G.**, How J. P., Output Feedback Concurrent Learning Model Reference Adaptive Control, AIAA GNC@SciTech, FL, 2015.
45. Axelrod A., **Chowdhary G.**, Efficiently Informed Exploration between Isolated Operatives for Distributed Systems, AIAA GNC@SciTech, FL, 2015, finalist for best student paper award.

46. Muehlegg M., Holzapfel F., **Chowdhary G.**, Trusting Learning Based Adaptive Flight Control Algorithms, Self-Confidence in Autonomous Systems, AAAI Fall Symposium Series 2015, At Arlington, Virginia, Oct 2015.
47. Roy S., Crick C., Maske H., **Chowdhary G.**, Teaching and learning using semantic labels, IEEE Human Robot Interaction, Breaking Report, Vienna Austria, March 2017.
48. Axelrod A., **Chowdhary G.**, Data-driven Prediction of EVAR with Confidence in Time-varying Datasets, RLDM 2017, Ann Arbor, MI.
49. Pattanaik A., Sui V., Osipychiev D., **Chowdhary G.**, Adversarial attacks on deep reinforcement learning, RLDM 2017, Ann Arbor, MI.
50. Joshi G., **Chowdhary G.**, Cross-Domain transfer learning using target apprentice, RLDM 2017, Ann Arbor, MI.
51. Maske H., Kieson E., **Chowdhary G.**, Abramson C., Learning instruction policy from demonstrations, RLDM 2017, Ann Arbor, MI.
52. Whitman J., **Chowdhary G.**, Learning Dynamics Across Similar Spatiotemporally Evolving Systems, Reinforcement Learning and Decision Making (RLDM) 2017, Ann Arbor, MI
53. Quindlen J., Topcu U., **Chowdhary G.**, How J., Active Sampling-based Binary Verification of Dynamical Systems, AIAA GNC@SciTech, Kissimmee FL, January 2018. ^
54. Choudhuri A., **Chowdhary G.**, Crop Stem Width Estimation in Highly Cluttered Field Environments, Computer Vision Problems in Plant Phenotyping 2018, Newcastle UK.
55. Choudhuri A., **Chowdhary G.**, Feasibility of Dimension Reduction and Reconstruction of Occluded Plants using Generative Adversarial Networks, AFITA 2018 workshop on phenotyping, Mumbai, India.
56. Whitman J., **Chowdhary G.**, Path Planning for Mobile Inference of Spatiotemporal Systems, NeurIPS workshop on Modeling and Decision Making in the Spatiotemporal Domain, NeurIPS 2018 (previously called NIPS), Montreal, CA.
57. Madhusudhan S. T., **Chowdhary G.**, Tonic Independent Raag Classification in Indian Classical Music, NeurIPS workshop on Modeling and Decision Making in the Spatiotemporal Domain, NeurIPS 2018 (previously called NIPS), Montreal, CA.
58. Guoxiang R., Tao L., Ying Y, **Chowdhary G.**, Ting K. C., Mobile robotics platform for a whole-poultry-house approach to egg production, ASABE annual meeting 2019, Boston, MA.
59. Joshi, G., Virdi J., **Chowdhary G.**, Design and Flight Evaluation of Deep Model Reference Adaptive Controller, AIAA SciTech 2020 Forum, Orlando, FL
60. Koe Kendall, Kamtikar Shivani, Uppalapati Naveen, Krishnan Girish, **Chowdhary Girish**, Visual Servoing for Pose Control of Hybrid Continuum Manipulator in an Unstructured Environment, CORL workshop, Nov 2023
61. Samhita Marri, Arun Narenthiran Sivakumar, Naveen Kumar Uppalapati, **Girish Chowdhary**, PlantTrack: Task-Driven Plant Keypoint Tracking with Zero-Shot Sim2Real Transfer in 40th Anniversary of the IEEE Conference on Robotics and Automation (ICRA@40), Rotterdam-Netherlands, 2024
62. Samhita Marri, Arun Narenthiran Sivakumar, Naveen Kumar Uppalapati, **Girish Chowdhary**, SkeleTree: Multi-View 3D Plant Skeleton Extraction in 40th Anniversary of the IEEE Conference on Robotics and Automation (ICRA@40), Rotterdam-Netherlands, 2024

G. Citations

[Google Scholar Profile](#), summary as of Jan 8, 2025



3. RESIDENT INSTRUCTION

A. Summary of Instruction

Courses taught at UIUC

CS 598 Advanced Topics in Mobile Robotics: Taught in Sp 24: *This course was introduced at UIUC by me.* The objective of this graduate course is to take a deep dive into advanced topics in perception, planning, and control for mobile robotics. There is a strong reliance on state-of-the-art results and project-based learning. Course is 4 credits.

CS 498 Mobile Robotics for Computer Scientists: Taught in Fa 21, Fa 22, Fa 23: *This course was introduced at UIUC by me,* The objective of this course is to prepare CS students in creating AI algorithms and software for mobile robot perception, planning, and control.

ABE 426/ECE 426 Principles of Mobile Robotics: Taught in FA 17, 18 as ABE 498 Principles of Field Robotics, in FA 19 as ABE 424, cross-listed as ABE/ECE 426 in FA 20: *This course was introduced at UIUC by me,* The objective of this course is to prepare students in designing and automating aerial and ground robots that operate in harsh, uncertain, and changing field environments. Course is 4 credit, approved for lab credit in ABE and ECE.

ABE 526 Autonomous Systems and Robots: Taught as Autonomous Decision Making in the Real World: Spring 17, 18, 19, *This course was introduced at UIUC by me:* The objective of this course is to prepare students in solving real-world problems by understanding and implementing the autonomy triad: perception, reasoning, and control on realistic systems. Course is 4 credit.

Courses taught at Oklahoma State University

MAE 5783: Principles of Autonomous Decision Making, *This course was introduced at OSU by me:* taught in Spring 14, 15, The objective of this course is to cover theory and techniques essential for building cyber-physical systems capable of autonomous decision making in the real-world.

MAE4053-ECEN4413: Automatic Control Systems, taught in Fall 13, 14, 15: This course covers the fundamentals of automatic control systems, starting with frequency response, bode plots, Nyquist plots, and root locus design, and then moving into state space design. The course had an online component and a Tulsa component, where students attended from a special remote-presence room.

Short courses and specialized courses

5 day course on AI for Outdoor Applications: This course is a short version of ABE 524 that is taught in 5 2 hour modules covering the basics of AI, machine learning, reinforcement learning, Kalman filtering, and adaptive control. Its intended at a graduate level to accelerate students working on robotics to get familiarity with advanced topics in autonomy and AI.

Taught at: IIT Kharagpur, Jan 2020

AI foundry for John Deere: This innovative 3 component course is designed to accelerate professional engineers in topics in AI for robotics. The first component is a 2 day intensive course focused on introducing the concepts at high level. The second component is a 4 month deeper dive with homeworks, 3 hours per week of remote instruction time, and 2 days per month of in-person lecture time. The third component is focused on executing a project that involves innovation with AI. Taught: Component 1, Aug 2019, Component 1, Feb 2020, Component 2, Feb – May 2020.

2) Supervision of Graduate Student Research

UIUC MS Students (Primary Advisor)

Name	Dates	Status	Thesis Title	Placement
Aditya Potnis (CS)	8/24 -		TBD: Topics in vision-based perception and planning for mobile manipulators	
Shivani Kamtikar (CS)	1/21 – 12/21	Graduated	Visual servoing for soft berry harvesting robots	UIUC PhD
Corey Davidson (ABE)	1/19 – 5/21	Graduated	Recreating NDVI images from RGB images	Aurora flight sciences
Junzhe Wu (ABE)	8/18 – 5/20	Current	3-D depth estimates with LIDAR and vision	UIUC PhD
Garret Gowan (AE)	2/18 – 5/20	Current	Adaptive control of hypersonic aircraft	Sandia
Anwesa Choudhuri (ECE)	8/17 – 8/19	Graduated	Autonomous robotic system for high throughput plant phenotyping (width estimation) in agricultural fields	UIUC PhD
Jasvir Virdi (AE)	8/18 – 5/20	Current	Adaptive control of unmanned aircraft	Industry
Beau Barber (ABE)	08/16 – 05/19	Graduated	Adaptive On-Site UAS based monitoring of large farms	UIUC PhD
Karan Chawla (ECE)	08/17 – 05/18	Graduated	Full Season Navigation and Control of Ultracompact Autonomous Agbot in GPS Denied Environment	SkyRyse Inc., CA
Wyatt McAllister (ECE)	4/17 – 5/18	Graduated	Multi-Agent Planning fo Coordinated Robotic Weeding	UIUC PhD
Sathwik Madhusudhan Tejaswi (ISE)	5/17 – 5/19	Graduated	Deep learning for tonic independent classification of Indian Classical Music	Schneider National, WI
Hunter Young (ABE)	6/16 – 5/19	Graduated	ROS-GAZEBO Farm Simulation Environment for Development of an Ultra Compact Autonomous Robot	Intelligent Automation Inc., MD
Tianhao Wu (ABE)	6/17 – 12/19	Current	Reinforcement learning for control of weeding arms	
Lukas Renker	1/18 –	Did not complete	End of row detection for agbots	Did not complete

OSU MS Students (Primary Advisor)

Sri Theja Vuppala	08/14 -04/16	Graduated (OSU)	Implementation and Validation of Gaussian Process Model Reference	UIUC Research Engineer
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			Adaptive Control for Fixed Wing Unmanned Aerial Systems	
Allan Axelrod	08/13 – 05/15	Graduated (OSU)	Learning to exploit time-varying heterogeneity in distributed sensing using the information exposure rate	UIUC PhD
Abdollahi Ali	08/14 – 06/16	Graduated (OSU)	Adaptive Multi-Objective Optimizing Flight Controller	Infinite8, Iran (startup)
Allamaraju Rakshit	01/13 – 12/15	Graduated (OSU)	Communication efficient decentralized sensor fusion in sensor networks	Unmanned Systems Research Institute (Stillwater OK)
Jaydeep Pabbisetty	01/13 – 12/14	Graduated (OSU)	Improving Navigation through Cooperation and Path Planning	Industry
Jacob Stockton	01/13 – 12/14	Graduated (OSU)	Modular Autopilot Design featuring Bayesian Non-Parametric Adaptive Control	Williams Companies, OK
Benjamin Reish	01/13 – 05/15	Graduated (OSU)	Concurrent Learning in Presence of Uncertain Input Allocation	OSU PhD

UIUC Ph.D. Students (primary advisor)

<u>Name</u>	<u>Dates</u>	<u>Status</u>	<u>Thesis Title</u>	<u>Placement</u>	<u>Department</u>
Shivani Kantikar (CS)	8/22	Current	Perception and control of soft robotic arms		CS
Shreya (Guna) Gummadi (CS)	8/21 -	Current	Federated learning for robot navigation		CS
Jose Currano (CS)	8/21 -	Current	SLAM in field settings		CS
Kendall Koe (CS)	8/21 -	Current	Robotic teams on an insect search and destroy mission in Soybean fields		CS
Kulbir Singh (CS)	8/21-	Current	Natural language programming for field robots		CS
Mateus Valverde Gasparino (CS)	1/20 -	Current	Traversability determination for autonomous field navigation		CS
Arun Sivkumar (CS)	8/19	Current	Visual navigation in agricultural fields		CS
Anwesa Choudhuri (ECE)	8/19 -	Current	Object Understanding in Generalized Video Segmentation	United Imaging intelligence	ECE
Ugur Akcal (AE)	8/19 -	Current	Neuromorphic computing for robotics		AE

Jiarui Sun (ECE)	1/20 -	Current	Bioinspired learning and control in soft bodied creatures		ECE
Justin Wasserman (ECE)	8/19 -	Current	Last-mile navigation		ECE
Wyatt Mcallistar (ECE)	8/18 – 5/20	Graduated	Models and Algorithms for Autonomous Weeding with Small Agbots	HRI Inc.	ECE
Harshal Maske (ABE)	8/14 – 8/18	Graduated	Learning Inference and Control for Construction Robots and Spatiotemporal Processes	Ford, MI	ABE
Girish Joshi (AE)	8/15 – 5/20	Graduated	Transfer Learning for Reinforcement Learning Domains	Mathworks	AE
Joshua Whitman (MechSci)	8/16 -	Graduated	Learning, Control, and Estimation in Feature Spaces of Machine Learning Models	UIUC teaching faculty	MechSci

Post-Doctoral Associates (primary advisor)

<u>Name</u>	<u>Dates</u>	<u>Research Area</u>	<u>Current position</u>
Hassan Kingravi	8/14 – 8/15	Machine learning	Equifax, Principal data scientist, GA
Erkan Kayacan	11/16 - 2/18	Robotics	University of Oklahoma, Assistant Professor
Aseem Borkar	8/19 – 8/21	Robotics	Newspace Technologies, Design Engineer
Andres Baqueros	3/19 – 7/22	Robotics	EarthSense inc., Autonomy Lead
Prabhat Mishra	6/19 – 2/23	Decision and Control Theory	IIT Kharagpur, Assistant Professor

4. SERVICE (PUBLIC, PROFESSIONAL/DISCIPLINARY, AND UNIVERSITY)

1) Technology Commercialization

Co-founder of EarthSense INC (www.earthsense.co): Commercialization of UIUC technology and economic development. EarthSense is also UIUC ARPA-E TERRA-MEPP project's official and required commercialization partner. EarthSense provides high-throughput phenotyping robots that are revolutionizing breeding, and over time, high-yield agriculture. EarthSense has raised over 1M in venture funds, won 2 SBIR Phase I awards and 1 SBIR Phase 2 award and is revenue positive. EarthSense currently employs over 10 full time, and several part-time employees.

2) Service to Disciplinary and Professional Societies or Associations

IEEE: Senior Member, serving as associate editor, reviewer, conference session chair, member of technical committees: Control and Decisions, Robotics and Automation

AIAA: Associate Fellow, serving as a reviewer, conference session chair, guest editor, member of technical committees: Guidance Navigation and Control, Intelligent Systems

ASABE: Member, involved in the joint IFAC (International Federation of Automatic Control)-ASABE committee on control in agriculture

ACM: Member**Workshops organized for professional societies**

1. **Workshop on Agricultural Robotics for a Sustainable Future**, with Naveen Uppalapati, Arun Narenthiran, Anand Kumar Mishra, Marija Popovic, Robert Shepherd, IROS 2023
2. **AI for Agriculture and Food Systems (AIAFS)**, with Aline Zare, Baskar Ganapathysubramanian, George Kantor, Katia Sycara, Koushik Nagasubramanian, Sierra Youn, Soumik Sarkar, and Soumyashree Karr, AAAI 2022
3. **Modeling and Decision Making in the Spatiotemporal Domain**, with Ransalu Senanayake (lead), Neal Jeans, and Fabio Ramos at the Neural Information Processing Systems (NeurIPS, previously known as NIPS) 2018, Montreal, CA.
4. **What's the Big Deal with Deep Learning, Girish Chowdhary (lead)**, Hassan Kingravi, Alex Schwing, Chinmay Soman, workshop at the IEEE Conference on Decision and Control (CDC), 2017 Melbourne, Australia.
5. **Collaborative Sensing, Learning, and Control in Human-Machine Systems**, Soumik Sarkar (lead), Nisar Ahmed, **Girish Chowdhary**, Workshop at the American Control Conference, 2016, Chicago IL.
6. **Intelligent Planning and Control: Bringing together Adaptive Control and Reinforcement Learning for Guaranteeing Optimal Performance and Robustness, Girish Chowdhary (lead)**, Tansel Yucelen, Frank Lewis, Warren Dixon, Lucian Businou, workshop at the IEEE Conference on Decision and Control, 2013, Florence Italy.
7. **Recent Advances in Model Reference Adaptive Control: Theory and Applications, Girish Chowdhary**, Tansel Yucelen, Preconference short-course, AIAA Guidance, Navigation, and Control Conference, Minneapolis, MN 2012.
8. **Recent Advances in Model Reference Adaptive Control: Theory and Applications, Girish Chowdhary**, Tansel Yucelen, Eric Johnson, workshop at the IEEE Conference on Decision and Control, 2011, Orlando FL.

3) University/Campus ServiceColleges and Campus UIUC

1. Director: **USDA/NIFA Farm of the Future**: Since 2022, a cross-campus research testbed for digital agriculture
2. Chief Scientist: **Illinois Autonomous Farm**: Since 2020, a testbed for autonomy research
3. **Grainger College of Engineering Research Growth and Diversification Strategic Planning Workgroup**: Workgroup member since February 22nd
4. **UIUC Center for Digital Agriculture**: Steering committee member since March 2018
5. **UIUC Center for Autonomy**: Key member advising activities in the center
6. **CSL Integrated Robotics Lab (IRL)**: Steering committee member since September 2017
7. **OTM Advisory Committee**: Committee member since December 2018
8. **UIUC Spicmacay Registered Student Organization**: Spicmacay works to promote Indian classical music and culture on campus, co-advisor of Spicmacay
9. **Department of Crop Science hiring committee**: Tenure track positions in digital agriculture

Department (UIUC)

1. **CS Hiring committee sub-chair for AI**: Fall 2022, Spring 2023
2. **CS hiring committee member**: Fall 2021
3. **CS Graduate Study committee**: Spring, 2021, Fall 2023
4. **CS Admissions committee**: Spring 2020
5. **ABE Department Head Search Committee**: Committee member since 2018
6. **Learning Outcomes and Assessment Plan Committee**: Committee member since 2016
7. **ABE Graduate Committee**: Committee member since 2017
8. **ABE Course and Curricula Committee**: Committee member since 2017

Department (OSU)

9. **MAE hiring committee**: Tenure track assistant professor in fluid dynamics

10. **MAE hiring committee:** Tenure track assistant professor in control systems

11. **US PERSON STATUS**

US Citizen

12. **COVERAGE IN POPULAR MEDIA (SELECT ARTICLES)**

1. [Researchers at U of I Lead Multimillion Dollar Futuristic Farm Project](#), anon. **News India Times**, June 17 2022
2. [Farming Drives Towards Precision Agriculture Technologies](#), Tom Johnson, **WIRED**, May 14 2022
3. [‘Farms are Going to Need Different Kinds of Robots’](#), Bernd Debusman Jr., **BBC News**, March 2021
4. [Toy Sized Tractor Drones Aim to Inspect Crops, Plant Covers](#), anon., No-Till Farmer
5. [A Growing Presence on the Farm: Robots](#), Knvul Sheikh, **The New York Times**, February 2020
6. [Swarms of Teeny Robot-Tractors Will Outmaneuver Tesla’s Driverless Cars](#), Sarah Kessler, **OneZero**, January 2020
7. [Follow that Furrow](#), Rory Jackson, **Unmanned Systems Technology Magazine**, March 2019
8. [What Will Tomorrow’s Ag Workers and Farmers Look Like](#), Fran Howard, **Agripulse**, Feb 2019
9. [8 Agtech Startups Worth Watching in 2019](#), Laurie Bedord, **Successful Farming**, January 2019
10. [Bots on the Ground](#), Shauna Rumbaugh, **High Plains Journal**, Oct 2019
11. [This Self-Driving Robot from U of I Could Shape the Future of Farming](#), Robert Holly, **Chicago Tribune**, April 2017
12. [Cross a John Deere with Roomba, and You Get this Crop-Monitoring Robot](#), Dyllan Furness, **Digital Trends**, March 2018