MedizDroids Project:
Ultra-Low Cost, Low-Altitude, Affordable and Sustainable UAV Multicopter Drones For Mosquito Vector Control in Malaria Disease Management

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***Abstract*— The goal of the MedizDroid Project is to research the affordable and sustainable use of aerial platforms (UAV, UAS, MAVs, drones, multi-copters and multi-rotors), briefly malaria mosquito control drones, for mosquito vector control and suppression. Mosquitoes are vectors for several diseases including malaria, Chikungunya, dengue fever, lymphatic filariasis (elephantiasis), West Nile virus disease, and yellow fever. Therefore, for each infectious disease, a very important aspect of integrated disease management is vector control.**

Current methods of mosquito control include using: a) Screens; b) Repellents; c) Insecticide treated bed nets (LLINs, ITNs, INs); d) Indoor residual spraying (IRS); e) Outdoor residual spraying (ORS): treatment of resting sites; f) Larval source management (LSM):treatment of breeding sites and water bodies; larviciding (LC); using biological controls (BC); g) Ultra-Low Volume (ULV) space spraying: aerial spraying; ground vehicle mounted spraying; h) External environment & habitat management, modification and manipulation (EHM*).

The focus of the Project is the automation of IRS, ORS, LSM (and later EHM*), in developing affordable and sustainable drone-based systems that can be deployed in malaria endemic sub-Saharan Africa and elsewhere. The current most realistic method of backpack spraying has many challenging issues.

Currently the Project is at the stage of specifying, simulating and prototyping subsystems: heavy lift and long endurance UAVs using hybrid power; composite and parasite drones; electronically controllable vector control payloads; and structured software platforms and architectures.

Keywords*— *uav, multicopter, drone, mosquito control, malaria, integrated vector management, larval source management, indoor residual spraying, outdoor residual spraying, autopilot.

I. INTRODUCTION

The strategic goal of the MedizDroids Project is to develop UAV (unmanned aerial vehicle) multicopter drones that can be used to automate key components of mosquito integrated vector control, in particular, indoor residual spraying (IRS) [1], outdoor residual spraying (ORS), and larval source management via larviciding (LSM-LC) [2], [3]. The primary aim is that the eventual integrated socio-technical systems are affordable and sustainable in malaria endemic countries in sub-Saharan Africa, South and South-East Asia, Central and South America, as part of the ongoing global efforts of malaria control, suppression, elimination and eventual eradication [4]. The current most practical and economic method for both indoor and outdoor spraying in the endemic areas is using manual backpack sprayers [1], [4]. The UAV multicopter drone based solutions are being investigated as replacements for expensive (helicopter and fixed wing aircraft) aerial spraying, ground vehicle spraying, and backpack spraying for mosquito vector control. Viable UAV drones for mosquito control are targeted for range of US $100 to US $500, fully-equipped, ready to fly (RTF).

Mosquitoes are vectors for the transmission of several infectious diseases including malaria, Chikungunya, dengue fever, Eastern equine encephalitis virus disease, Japanese elephantiasis, lymphatic filariasis (elephantiasis), Ross River fever, West Nile Virus disease, and yellow fever. Therefore, for each infectious disease, a very important aspect of integrated disease management is integrated vector management [5], [6], [7], [8].

The automation of mosquito vector control tasks requires a thorough understanding of the mosquito: its entomology, life cycle, bionomics, ecology and various behaviors: oviposition (egg laying), biting, host-seeking, blood-feeding, resting.

There are about 2,500 species of mosquitoes. Maybe 7 are vectors for transmission of human malaria, mainly from the genera Anopheles, Aedes and Culex.

The life stages of the mosquito life cycle are: Adult → Egg → Larva → Pupa → Adult. Fig. 1. shows the life stages and their relation to integrated vector control tasks. Backpack spraying [1], [4] poses several significant challenges. It belongs to the DDD ("dirty, dull and dangerous") work category. It is tedious, routine, repetitive and back breaking; it sometimes requires operating in inaccessible, dangerous and wet locales and poor weather conditions; field operators face potential health risks due to frequent exposure to insecticides; the current methods of outdoor spraying are imprecise and inefficient, and wasteful of very valuable chemical assets; and there is a lack of control as well as profligate use insecticide supplies, with implications for insecticide resistance. It is also time consuming, labor intensive, requires discipline, precision, professionalism; and the need to for humans to operate in complex socio-technical environments. It is clearly a task domain that is ripe for affordable and sustainable automation. UAV multicopter drones will support precision spraying, whereby local conditions are used to determine the dimensions of the area to be sprayed, and amount of insecticide to use.

II. Current Results & Discussion

The MedizDroids Project is a recently established and an ongoing project. The accomplishments of the project to date include: a) a thorough understanding of the research and development challenges involved in using UAV multicopter drones for mosquito vector control; b) re-engineering a software architecture for extant multicopter Autopilots; c) specifications of functional requirements for hybrid, semi-autonomous flight control of multicopters; d) specifications for use of hybrid power; e) computational models for the automation of the IRS, ORS and LSM-LC vector control tasks.

A. Research Challenges

Initial investigations under lab conditions indicate that UAV multicopter drones intended for mosquito vector control must meet several requirements.

- **Heavy-Lift**: Able to carry 1 to 5 gallons of insecticide (Notes 7), [4], [7], [8].
- **Hybrid Power**: (ICE + battery): Flight time duration should improve from current 15 min - 40 min to 5+hrs
- **Green Energy**: Renewable sources of energy to charge battery: micro-hydro, pico-hydro, solar, micro-wind turbines
- **Long Endurance** and **Range**: primarily dependent on using hybrid power.
- **Multi-copter complex flight maneuvers**: Including hover, loiter, station keeping, stare; stabilized flight during precision spraying; drone mimicking of tethered aerostats
- **Dual or Multiple Control Modes**: ***Remote Control*** (Tele-operation); ***Autonomous*** (pre-programmed, hands-free); ***Hybrid*** (semi-autonomous) flight controls.
- **Payload Adaptors:** IRS, ORS, LSM, EHM, ESA electronically controlled payloads using electronic control units (ECU); 3D printing style spraying. Isolation of aircraft from diverse payloads.
- **Dual Use** or **Multi-use**: for Affordability and Sustainability; E.g., for Vector Control and Agriculture.
- **Drone Flotillas**: swarms, mother ship + daughters (dronelets), Swarmdronebots, SwarmDrones, DroneNets.
- **Wireless sensor networks, distributed sensor networks**: specialized airborne sensors for: flight operations, proximity, collision avoidance, sense-and-avoid, domain-specific task operations, field deployable biosensors and lab-on-a-chip for automated entomological surveillance, larval surveillance, environmental surveillance and insecticide surveillance.
- **Robots integration**: task specialists: aerial, ground, water surface, underwater, indoor, outdoor, off-road
- **Autonomics**: Self-* behaviors (self-configuration, self-management, etc.)
- **Agent** Based Models (ABM), Multi-Agent Systems (MAS), **Parallel bots**, agents, services.
- **Service choreography and orchestration (SCO):** domain tasks-as-services in service oriented architectures (SOA).

Meeting these challenges for deployable systems include specifications for materials used for airframes; power and energy sources; computing hardware and software; and materials, equipment and supplies used for vector control tasks. For the aerial platforms, one needs to specify requirements for Endurance, Autonomous Operation, Maneuverability, and Payload Automation and Performance.

B. Computational Models for Automating LSM-LC

Larviciding requires treatment of water bodies that serve as breeding sites and larval habitats [2], [3]. The LSM-LC task layers for automation are: Pre-mission, Mission & Co-mission, Post-mission operations.

- ***LSM-LC Pre-mission***: Outdoor site & environmental survey, mapping, preparation and sensor placement; insecticide procurement, storage and management; outdoor entomological survey; spray staff instruction and training.
- ***LSM-LC Mission & Co-mission***: Doing actual larviciding spraying and application.
- ***LSM-LC Post-mission***: Work completion verification: spot checks, surveillance, monitoring; Insecticide management.

Core LSM-LC Mission tasks to be automated are:
Home Base-to-Field Site tasks: Travel; Transportation; Flight, Navigation; Resource Replenishment.
Site Field Operations tasks: Site treatment; Larvicide application; Water surface oiling; Water surface coverage with expanded polystyrene (EPS) beads; Field Operations-to-Home Base (HQ) Interactions

Field Site-to-Home Base tasks: Return Travel; Return Transportation; Return Flight, Navigation.

LSM-LC Post-mission tasks are concerned with assessment, re-visits, surveillance, and monitoring.

Automating actual larvicide spraying requires the following deliverables to be engineered.

1. Identification, targeting and delineation of breeding site (larval habitat) as landscape area.
2. Division, partitioning into parcels, land plots (tiling, tessellation). One can use polyominoes to represent breeding site areas, a form of quilt-making.
3. Consolidation of the primary parcel tiles into poly-tiles so that every water body at the breeding site is completely contained or enclosed within a poly-tile.
4. Characterization of parcel (poly-)tiles according to occupancy of water bodies: count, shapes and spatial distribution
5. Pixel or raster image representation of each parcel (poly-) tile. This approach avoids the difficulties involved with a vector graphic representation, according to sizes, shapes, perimeters, boundaries, contours.
6. Actual spraying operation will involve two major activities: a) inter-tile traversal, tour, trace, navigation; and b) intra-tile detailed operations, during a visit, sojourn at a parcel (poly-) tile.

Inter-tile traversal can be automated as waypoint-to-waypoint navigation according to a schedule defined by a space filling curve (SFC). There are several candidates of SFC (N-dim to 1-dim indexing mapping) that can be used, including: Hilbert, Peano, Z-order or Morton, H-order, Moore, Lebesgue, Balanced, Gray code, etc., [9], [10]. The actual spraying of a parcel (poly-) tile can be likened to pixel rendering in raster imaging. As noted above, each parcel (poly-) tile is re-gridded or rasterized into pixel-like elements (pixeloids or pixelets). The class of algorithms variously known by the terms plane sweeping, scan line, (progressive) raster scanning, non-interlaced scanning, can be used. When a pixeloid is reached, it is either not sprayed (skipped) or sprayed according to a prescribed intensity, chosen from a finite discrete set of possible values.

C. Computational Models for Automating IRS

IRS [1] requires spraying insecticide (adulticide) on interior and exterior walls, living space and bedroom structures and fixtures, in order to kill adult mosquitoes which are biting or resting indoors. The IRS task layers for automation are: Pre-mission; Mission & Co-mission and Post-mission.

- ***IRS Pre-mission***: Indoor site & household survey, mapping, preparation and sensor placement.
- ***IRS Mission***: Doing actual IRS: house-to-house, shelter-to-shelter, room-to-room, wall-to-wall.
- ***IRS Post-mission***: Verify IRS has been done: spot checks, surveillance, monitoring and tracking.

Automating the core task of **IRS**, actual spraying, include: 1) **Locate** House, Building, Shelter, Room, Level/Floor/Room; 2) **Enter** Room through doorway, entrance, entryway, gateway; 3) **Visit** Walls, Ceiling, Floor according to planned Schedule; 4) For each wall, locate and visit; **Spray** systematically in swaths: **spraying multi-robots**; 5) **Exit** Room through doorway, exit.

The technologies to support the IRS task automation include: a) **BREP** or **B-rep**: Boundary Representation [11], [12] of building interiors; and b) Simultaneous Localization and Mapping (**SLAM**) of spatial entities and structures [13], [14]: Environment SLAM (Self-SLAM) and Visitor SLAM (Drone-oriented SLAM). The approach adopted in the Project is the use of pre-installed sensors vs. real-time, dynamic (on-the-fly) construction (Fig. 2).

D. Software Architectures for Structuring Multicopter Autopilots and GCS Software

Most of the extant multicopter autopilots and GCS (ground control stations) software, for civilian uses, especially the hobbyist and FOSS (free open source software) versions, such as ArdupilotMega, Open Pilot and Paparazzi [15], are currently not structured to meet stringent software engineering requirements. The MedizDroids Project is in the process of creating a software architecture for multicopter autopilots using several technologies: service oriented architecture (SOA); Services Choreography & Services Orchestration (SCO); services-as-agents, bots; service adaptors; service virtualization and abstraction, (see Fig. 3).

One of the advantages of the software architecture approach is that new flight mission modules can easily be plugged into the structured framework. Furthermore, different components of the UAV multicopter drone can readily be replaced by improved substitutes. Finally, the software architecture facilitates the programming, since each component or sub-system can be regarded as an abstract data type (ADT) with functional specializations organized into domain-specific hardware and software application programming interfaces (HAPI) and (SAPI).

E. Hybrid Semi-autonomous Control of Multicopters

To further enhance the proficiency and in-flight configurability of the multicopter autopilot, the newly developed service oriented architecture (SOA) embedded in the semi-autonomous multicopter will communicate with the Ground Control Station (GCS) using Open Source hardware and GCS protocols including MAVLink (Micro Air Vehicle Communication Protocol). Current worldwide MAVLink GCS projects include; QGroundControl, HK Ground Control Station, and APM Planner. Although well documented, open-source, and inexpensive, the telemetry hardware and software available at the hobbyist level cannot facilitate the implementation of the newly developed mission modules at the subsystem level. Therefore, the MedizDriods project is currently in the process of reconfiguring Ground Control Station FOSS (free open source software) to communicate with multiple semi-autonomous drones determining Control Modes, Payload adapters (IRS, ORS, LSM, EHM, ESA), and Flight Mission Service Modules.

The Ground Control Station (GCS) consists of readily available, Microsoft Windows-based, computing hardware and telemetry control module. In conjunction with the GCS program and UAS (unmanned autonomous systems) service oriented architecture (SOA) developed for the MedizDroids project, the (hardware-based) telemetry control module communicates directly with the Electronic Control Unit (ECU) and Enterprise Service Bus (ESB) of the multicopter. This two way data link provides access to the hardware application programming interfaces (HAPI) to provide real-time analysis of the data received by the UAV while also providing mission alternatives and updates based on information acquired by other data sets.

The operational MedizDroids deployments are anticipated to be more cost-effective than the existing manual (mainly backpack based) methods of mosquito integrated vector management. The analysis shows potential savings in labor costs; equipment costs; human worker safety, protection and health; insecticide use; and insecticide resistance management (IRM).

III. Future Research and Future Work

The remaining phases in the MedizDroids project plan include the following steps.

Phase 2: Indoor (Gym) Testing

- Integration of components and subsystems into complete MedizDroids platforms.
- Perform, document and assess vector control tasks in an indoor gym.

Phase 3: Outdoor Soccer or Football Field Testing, Proving Ground

Phase 4: Outdoor Field Testing in Villages

- Test complete and integrated proof-of-concept systems in 3 village communities in Africa, one in each of West Africa, East Africa and Southern Africa.

Phase 5: Conversion into Deployable Products, Systems and Infrastructures

- Complete the final engineering specification of the MedizDroid eco-system that meets all the stated requirements of Affordability, Sustainability, Maintainability, Reliability, Robustness, Usability, and various other (engineering) "iLities".

Phase 6: Operational Deployment in Village Communities and Urban Settings.

Overall, it is estimated that it will take about 3 years from project launch to initial deployment of first generation operational systems in village communities in Africa and elsewhere in developing countries.

IV. Related Work

The MedizDroids Project is one of the first public projects explicitly devoted to using UAV multicopter drones for mosquito vector control (Notes 2). It certainly is the only project currently devoted to building affordable UAV multicopter drones for mosquito integrated vector management in malaria endemic countries, especially in sub-Saharan Africa. UAV drones have started to be used in agricultural applications: crop spraying, aerial imaging and precision agriculture (Notes 1-2, 4 ,6) and some of the results can be leveraged for mosquito integrated vector management.

SLAM technology is used extensively in vacuum robots for floor cleaning, such as Neato's products.

Research into structured software for UAV multicopter drones has just begun and will certainly accelerate with widespread deployment of civilian applications [15], [16], [17], [18].

V. Summary & Conclusions

The primary goal of the ongoing MedizDroid Project is to modernize and automate the current practices of indoor residual spraying (IRS) and larval source management / larviciding (LSM-LC) by introducing precision vector control. The only method for both indoor and outdoor spraying which is currently considered practical and economic, in the designated geographical regions, is the use of human sprayers, with the spraying equipment and liquid insecticide carried around as a portable backpack.

The Project is currently in the phase of computational modeling and knowledge representation to support the automation and integration of the application and domain specific tasks. A lot of technologies and tasks need to be integrated and choreographed as services, and the systematic structured approach adopted in the Project is essential to achieving such coordination.

Successful MedizDroids platforms can become important components in global health integrated disease management, via mosquito vector control, suppression, reduction and mitigation. For malaria elimination and eventual eradication, MedizDroids platforms can be used as subsystems in the related Keep Out Malaria (KOM) Project to create mosquito-free zones (MFZ).

The ultimate primary results of the MedizDroids Project will be the engineering specification of the socio-technical architectures and deployment tactics for affordable and sustainable MedizDroids. The Project results will then be assessed by the impacts MedizDroids deployments have on malaria disease transmission and morbidity.

VI. Notes

1. The Yamaha RMAX miniature helicopter drone, developed in the 1990s has been used extensively for spraying and crop dusting of rice paddies in Japan. It is estimated that it is currently being used for 40% of the rice paddies in Japan. The cost of Yamaha RMAX drone is US $100,000 to US $230,000, depending on the accessories, such as GPS, that are included in the deployment. The drone typically carries a 4-gallon payload to spray a 5-acre rice paddy. It can spray 12 to 15 acres per hour. In contrast, a tractor-mounted system can spray at the rate of 2 acres per hour.

2. The Yamaha RMAX is now being used as an agriculture drone in vineyards in Napa Valley, California; and outdoor aerial spraying of insecticide in St Augustine, FL.

3. Florida Keys Mosquito Control District (FKMCD) (August 2013) conducted pilot tests using the Maveric drone (UAV) based on University of Florida research. The drone was equipped with (IR) thermal cameras to scan and detect breeding sites for the black salt marsh mosquitoes. The tests deliberately and intentionally excluded actual spraying and killing of the mosquitos at the breeding sites that were found. The cost of the drone and support system was US $65,000.

4. Utility Robotics LLC, a consulting company, built the Microspray System for “pinpoint applications and pesticides and chemicals” in using drones to spray rows of crops in agriculture.

5. 3D Robotics is building drones for commercial use, US $500 – US $700. It also sells the US $700 Iris drone, with remote control from PC and Android phones. The autopilot used, ArdupilotMega, from DIY Drones, can be used to convert any hobbyist remote control aerial platform, and it costs about US $149.

6. UAV drones currently targeted at agriculture applications cost US $50,000 – US $100,000. Such drones are available from DMZ Ariel, Honeycomb UAS, among others.

7. According to [4], backpack or knapsack sprayers in the US typically have capacities of 2 to 5.5 gallons, and the typical weight to be carried by the human sprayer is 25 lbs to 75 lbs.

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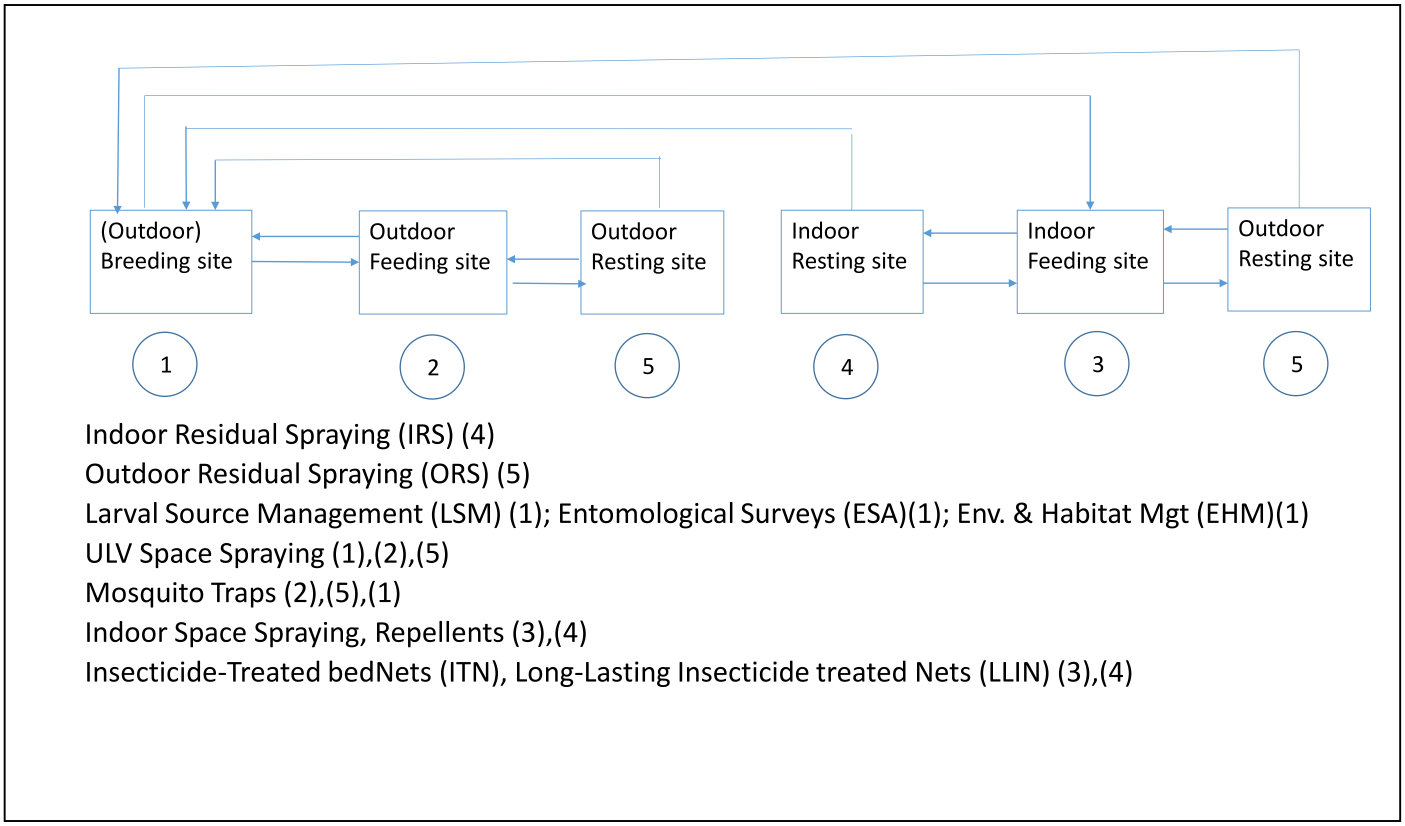

Fig. 1. Mosquito Control Tasks

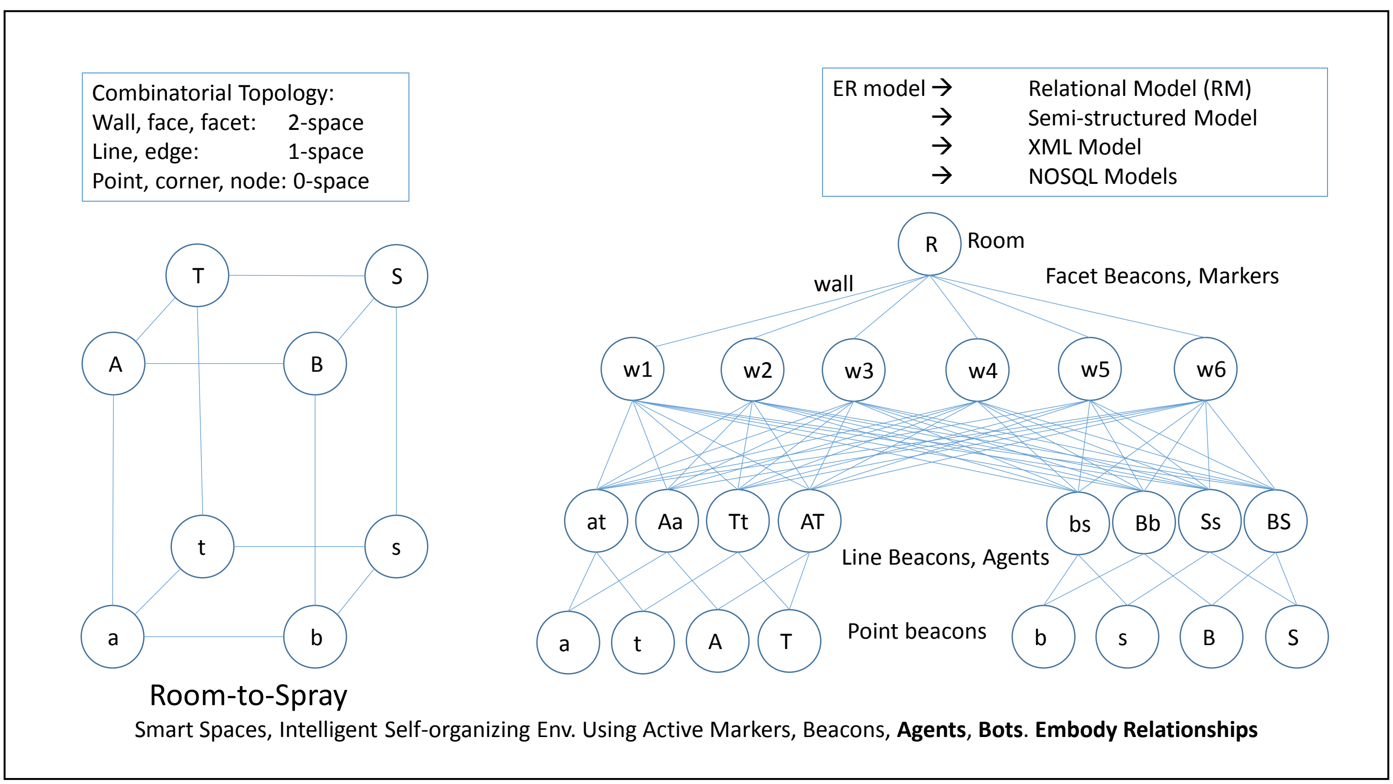

Fig. 2. Boundary Representation of Building Interiors and Environment Sensor Tagging for SLAM in IRS task automation

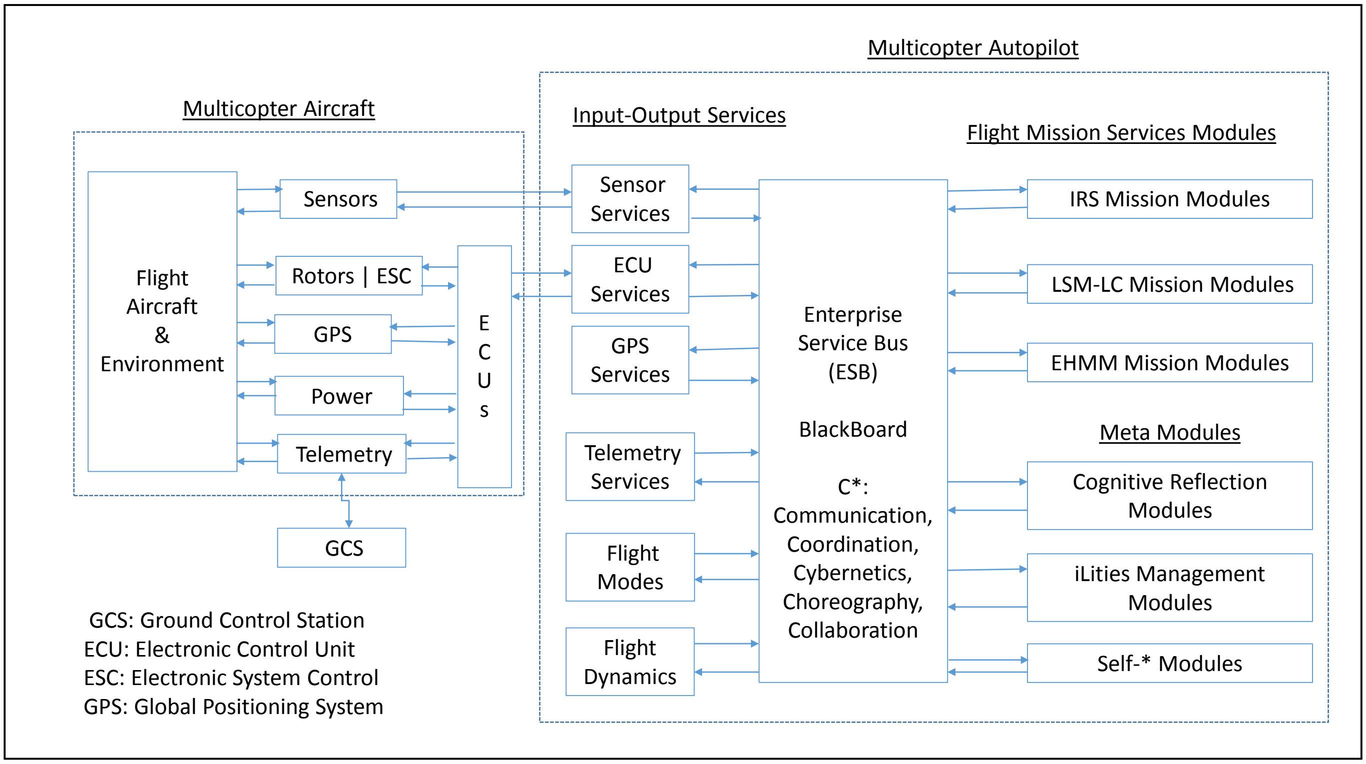

Fig. 3. Service Oriented Architecture Model of a Multicopter Autopilot