Smart Living - Personal and Service Drones

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***Abstract*—This paper introduces concepts of Personal Drone and Service Drone and describes four scenarios showing how personal drones and service drones may be used. Both concepts are mapped to the concept of Smart Living since their relationship is essential. The overview of Personal Drone and Service drone concepts and use cases preceded by an analysis of drone state of the art and future trends collected from the most recently published commercial reports. The future development of state-of-the-art along with user perception, legislation and policies will form a solid ground for both concepts to be implemented in the future.**

I. INTRODUCTION

In this work, all lightweight aircrafts typically referred to as Unmanned Aerial Vehicles (UAV), Unmanned Aerial Systems (UAS), Remotely-piloted Aircraft Systems (RPAS) [1] will be referred to as drones.

The history of drones started with military applications. In 1849, the Austrian army used about 200 hot-air balloons to bomb Venice [2]. Gradually, from a variety of military applications [3], drones spread to commercial and civilian [1], [4], [5]. Commercial Drone Industry report [6] states that in 2018 drones are used in ten industries with major applications in Agriculture, Construction, Surveying, Real Estate and Mining.

Commercial Drones - Global Strategic Business Report [7] highlighted several market trends and important issues associated with drone business. Among the trends, the further development of Artificial Intelligence (AI) and the Internet of Things (IoT) will continue to drive market growth. Falling costs of body materials and advancing smartphone technologies will continue to facilitate commercial applications of drones. Enterprise sector will demand more drones for gathering data. A significant development of automation technologies will take place, as well as 3D mapping technologies for both, mission performance, and data gathering target. Smart capabilities will boost adoption of photography drones. Speaking of development of drone technologies, the main focus will be on battery technologies. More Open Source drone design will be seen. A growing concept is Drone Rental Centres – to spread drone applications with a low average cost of ownership. Drone-as-a-Service concept will emerge for the enterprise world. [7].

Drone Technology and Global Markets report [8] breaks down drone classification to the following types: Unmanned Surface Vehicles (USV), Unmanned Ground Vehicles (UGV) and finally Unmanned Aerial Vehicles (UAV). This classification does not include consumer's driverless cars. Use of drones in end-user industries is anticipated for agriculture, medical and surgical purposes, security, defence, and ocean and space. Among the main applications defence, logistics and warehousing, field operations and entertainment are listed. [8].

Small Drones Market: Global Forecast until 2025 report [9] predicts small drone market grows from about 13,4 billion USD in 2018 to about 40,3 billion USD in 2025. Among the industry trends that are not highlighted in other reports, are 3D printing of small drones, multi-sensor data fusion, cloud computing-based services, endurance in small drones, superior computing technologies for small drones, improved payloads, appearance of automated ground control stations, spread of swarm drones, wider applications of spy drones, new type of drones such as inflatable, further development of anti-drone defence systems, and more sophisticated drone insurance policies. Among the power sources, lithium-ion, solar cell, fuel cell and hybrid cell are mentioned. [9].

Similar forecast has been given by Small Drones Market by Type (Fixed-Wing, Rotary-Wing, Hybrid/Transitional), Application, MTOW (<5 kg, 5–25 kg, 25–150 kg), Payload (Camera, CBRN Sensors, Electronic Intelligence Payload, Radar), Power Source, and Region - Global Forecast to 2025 report [10]. The market estimated to grow from about 9,71 billion USD in 2017 to about 40,31 billion USD in 2025. The following estimate for small drone's application domain is given [10]:

- Military
  - Intelligence, Surveillance, and Reconnaissance (ISR)
  - Battle Damage Management
- Civil and Commercial
  - Precision Agriculture
  - Remote Sensing
  - Inspection Monitoring
  - Photography & Film Production
  - Surveying and Mapping
  - Product Delivery
  - Wildlife Research & Preservation
  - Scientific Research
  - Media Coverage
- Homeland Security
  - Border Management
  - Traffic Monitoring
  - Fire Fighting & Disaster Management

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  - Search & Rescue
  - Law Enforcement
  - Maritime Security
- Consumer
  - Prosumer
  - Hobbyist/DIY

With respect to payload, small drone market will utilize Electronic Intelligence Payloads, high-resolution, multispectral, hyperspectral, thermal and Electro-Optical/Infra-Red (EO/IR) cameras, chemical, biological, radiological, nuclear, or explosives (CBRNE) sensors, and Synthetic Aperture Radar (SAR) or Active Electronically Scanned Array (AESA) Radar [10].

IDC's Worldwide Drone Taxonomy, 2018 report [11] defines the following types of drones: Fixed-Wing, Multirotor, Helicopter, Vertical Take-off and Land and Tethered Rotary Wing drones. The report also highlights Drone-as-a-Service paradigm. The key notions are the following: Beyond Visual Line of Sight, First-Person View, Flight Management Unit, UAS Traffic Management, Low Altitude Authorization and Notification Capability, Drone Operator, Drone Aircraft System. Key drone subsystems are the following: Communication Link, Radio Controller, Propulsion Systems, Sensors, Airframe. [11].

What is missing yet in the worldwide picture of drone applications, is a rise of personal drones and consumer-oriented service drones.

The rest of this paper is structured as follows. A brief overview of smart living concept concerning drones is given in Section II. In Section III, a personal drone concept is introduced. Service drone concept is introduced in Section IV. Several scenarios where personal and service drones are utilised are described in Section V. Concluding remarks are given in Section VI.

II. Smart Living

The Smart Living concept [12][13] brings understanding that human life is not limited to home area and therefore Smart Home concept that was traditionally used to address all the demands for digital services supporting every-day activities was not sufficient enough. Further elaboration of the concept of Smart Living discovered new domains and broader relationship between smart spaces and different aspects of human lives, expanded the view of smart spaces and found that they share many similarities and common technology challenges [13],[14],[15],[16].

Quite many aspects of human living, such as education, work, cultural and social life, range beyond those living environments where Smart Homes operate. The concept of Smart Living essentially assumes all the aspects of human living being affected with technologies. [16].

Smart Living is a concept of building people-oriented lifestyles supported by a smart environment that consists of smart spaces – interoperable, and possibly nested or intersected. Smart City, Smart Home, Smart Office, Smart University, Smart Factory, Smart Library, Smart Community, Smart Hospital, and many others are examples of smart spaces. The ultimate goal of the Smart Living is to help people to be happy through a high quality of life and health and pursue sustainability of resources [16][17].

The main strength of the Smart living concept is in reusability, adaptively, scalability and sustainability of its solutions across the smart spaces. It has been discovered that quite many technological challenges are similar regardless of a smart space and its domain [16].

Understanding that may bring to the development of more unified and reusable solutions that could be reusable across smart spaces and domains. [16]. For example, Light Fidelity (Li-Fi) wireless communications may be used in home automation solutions [17] in such smart spaces as Smart Home, Smart University, Smart Hospital or Smart Factory, and at the same time Li-Fi communications may be used for communications between drones operating indoor in the same smart spaces, even though that kind of communications is not suitable well for drone swarms [18].

Development of solutions within the Smart Living concept assumes:

- involvement of a diversity of technology enablers (such as AI, IoT, Cloud Services, Edge Computing, Semantic Web, blockchain, printed electronics, wireless communications, energy harvesters, etc.)
- in a great number of application areas (such as health and wellness, education, government, commerce and retail, culture, art, etc.)
- and a variety of business domains (service, health, banking, industrial, manufacturing, mechanical, construction, energy, transportation, farming, etc.).

Drones are very good examples of solutions following Smart Living concept. An AI-enhanced and cloud services supported small drone that uses advanced battery and energy harvesting technologies and carries a variety of sensors or even tiny manipulators, may operate autonomously indoor and outdoor in different smart spaces and carry our missions of different purposes.

That kind of drone, by interacting with intelligent systems of those smart spaces and communicating with its user using his/her smartphone or built-in to smart spaces interfaces, may act as a personal assistant. Or, a larger and more advanced version of drone having a big operation range, able to transport packages and use a multi-purpose robotic arm and equipped with a wide range of different communication means, by being supported with a sophisticated operational infrastructure, may carry out duties of service drone and support operations of personal drones.

III. Personal Drones

For personal assistance, capable smart spaces running appropriate services may provide a user with a variety of interfaces. Among those interfaces may be different screens, smartphones, smart glasses, multimodal virtual instances and instances of augmented and virtual environments. Some of those interfaces are portable enough to be carried by a user;

some may follow him/her virtually. But those cannot follow the user physically. Moreover, those cannot interact with the real physical word. For that, other entities are needed, such as actuators, manipulators, and robotic arms.

Robotic equipment operating in smart spaces may interact with the real physical world and at the same time provide a user with smart spaces' interfaces. Service robots designed for Ambient Assisted Living (AAL) are good examples of those. Among the disadvantages of robotics are relatively higher costs, the complexity of operations on busy floor areas and poor ability to follow a user outdoor. Probably the first drone able to follow a user for shooting videos and photos was Lily [19]. Now many consumer drone vendors equip their products with functionality making drones able to follow their users, for example, Follow Me by DJI [20].

Even though disadvantages of drones such as small operation time and range, noise and relatively small payload are well known, they have definite advantages comparing to robots operating on a ground/floor. Drones operate in the air, can move relatively fast, and are not affected by irregularities and business of the ground area.

Integrating drones into the smart systems operating smart spaces may significantly improve user experiences and enable a broad range of digital services that have never existed before. Personal drones may differ by size and purpose. Some may be able to follow a user as a tiny personal assistant; some may be able to deliver small items within the allowed payload and ability to grab physical artefacts. There may be several personal assistive drones in the household for every member of a family. Some of those may be able to follow a user outdoor or even further, to other smart spaces, such as Smart Factory, Smart University, Smart Hospital, etc.

Autonomous personal drones, as well as other autonomous robots under certain circumstances, may be acknowledged as pets, some kind of living instance able to model emotional outcome and express it. Drones for example, by waving or bouncing vertically or horizontally, or shaking sides or front-rear, may express agreements, disagreements, happiness or disagreement. The range of expressions may be extended status indicators and even auxiliary light sources of drones. Even more, tiny speakers and microphones may be built-in to drones for voice communications.

Those are just the onboard means that personal drones may utilise to communicate with their user. The other means are the user's smartphone and interfaces provided by the smart environment. For example, Smart Home's TVs, screens, and interactive walls and windows may enhance drone-to-human communications.

There are many technological challenges and barriers associated with the implementation of personal drones. Operation range and flight time are probably the strongest. The other is the availability of strong AI and computation power, efficient wireless communications, optimised for low-noise propeller technologies, the well-developed infrastructure supporting operations of personal drones in smart spaces and even outside of those.

Speaking of AI, not only AI engine of smart spaces may be utilised to build a drone intelligence, but also AI-enhanced virtual digital assistants developed by Amazon, Apple, Google and Microsoft: Alexa, Siri, Google Assistant and Cortana. The mentioned companies develop their smart home solutions that may simplify integration of personal drones with their systems in the future.

In Smart Home space, personal drones may be able to carry out dedicated operations, or interact with other home drones, such as airbrush swarm, dusting drone, lawn manicuring drone, leaf raking drone, home security drone, repair drone, or even diaper changing drone [21]. Personal drones may be able to deliver medicine or heavier item, like smartphone or even a cup of tea; make injections or take blood tests; monitor the status of health and body, take care of nails and skin; analyse physical activities and habits; monitor environment conditions and act as remote eyes; entertain, alert, educate, coach, mentor, guide; be security unit or a butler.

What is very important about autonomous personal drones is that they do not have fly around the person they serve all the time. There may be several docking stations around the household where personal drones may stay and get charging at the same time. The charging can be organised through special connectors built-in to drones' legs, or wirelessly. The idea is that the personal drone lands to the nearby docking station and waits to be called by a person it serves. When the person leaves home, the personal drone may follow the person in the air – for a short time, till the next nearest available docking station – or eight away in a special container.

The container may provide charging, additional sensors and communication means and the like. Mobile or stationary container or docking stations may be implemented in the form of boxes or be flat. Some part of those or their entire surface may be implemented as a solar panel to harvest energy. Outdoor versions of those docking stations may additionally be equipped with small wind turbines to extend their energy harvesting abilities. Several versions of solar-powered pads for contact and wireless charring of drones are researched and even commercially available [22],[23].

Docking stations may be equipped with or connected to wind turbines or solar panels that are parts of docking stations' constructions or available for this purpose, or to the electric grid. For the last, business processes involving monetary relationships may need to be developed as well as technologies able to identify personal drones, check payment means associated with them, and measure the energy consumption of those drones getting charged at the publicly available docking stations.

Public transportation vehicles may be equipped with dedicated containers or heliports for transporting and charging personal drones. Publicly-available charging stations around the city may improve user experiences. Moreover, personal cars may be equipped with docking containers, stations, or heliports for transporting and charging personal drones. First attempts to do so already appeared [24]. A personal drone attached to a car may help the car to harvest energy [25].

IV. Service Drones

Drone-based delivery and logistics improve efficiency and quality of delivery services and support low-carbon economy [26],[27],[28],[29],[30],[31]. Operating range and payloads of drones are great technical challenges restricting drone-based delivery yet, not mentioning structural and organisational challenges.

A model of range-restricted recharging station coverage for drone delivery service was proposed [32] to expand the operating range. In harsh weather conditions, more protected versions of charging stations may be used, supported with appropriate infrastructure, similar to those that are already commercially available [33]. The concept of service drone though is much wider than drone-based delivery.

The concept of service drones implies masses of multi-purpose and specific service drones publicly available for a great variety of services in urban and even rural areas, where supporting infrastructures and a vast number of multi-purpose heliports are deployed. Service drones could provide services to private people, public and even commercial organisations.

Service drones may interact with personal drones and support their operations when needed. A draft sketch of different elements of personal drone and service drone interactions and supporting infrastructure is shown in Fig. 1. The sketch was developed as a part of teamwork [34].

Among the services that service drones may provide are: facilitating last mile, just-in-time, dynamic location change or multi-hop delivery; involvement in first responders and search and rescue operations; on-demand monitoring and observations; entertainment and show-making; informing, warning, alerting and guiding means; remote eye, photo and video on demand; arranging sport and public activities; affecting reality – animals or insects such as mosquitos, or changing physical properties, such as odour, sound, light or temperature.

Multi-purpose drones are those that may operate to deliver a broad range of services. For that, they may need to be able to autonomously swap the multi-tool module to something more specific at the multi-purpose heliports. For example, a cargo module may be changed to a robotic arm, or an advanced camera module, or a sensor module, or a block of light-emitting lamps. Among the special purpose service drones, drone taxi, heavy cargo or cleaning drones may be listed – any of them may be called upon demand.

Supporting infrastructure includes integration to business models, supply chain and service provisioning schemas, availability of interfaces, including end-user, a broad range of communication means covering all operational areas, drone identification and tracking methods, traffic management, power supply infrastructure enhanced with energy harvesting technologies, rules and policies.

Multi-purpose heliports serve for parking and charging of service drones. They may be equipped with a variety of modules that service drones can swap in order to achieve the best match for the requested mission. Heliports may be equipped with cargo bays or lockers able to fix a cargo container left by a service drone and to be picked up by the next service drone of a delivery chain.

Heliports may be of different size – to be able to accommodate an appropriate service drone and volume – depending on a functional purpose. For example, a drone taxi heliport may be of the significant area and accommodate several taxi drones. Heliports to supply service drones with a range of tools and accommodating cargo, especially providing environmental protection, may be quite bulky. They may also be equipped with vandalism and anti-thief protection. This kind of heliports may be placed to public areas, on roofs of buildings, or on tops of heavy construction's elements. Taxi drone heliports may be located in easy-to-reach areas.

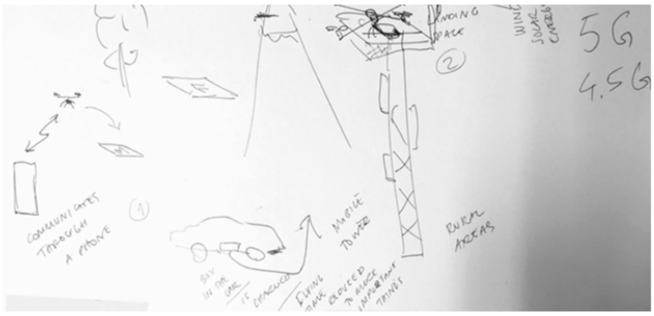

Fig. 1. Team work: Service Drone and Personal Drone concepts

For relatively small service drones, heliports may have as small area as portions of a square meter. Light versions of heliports, those that serve for parking and charging purposes only, may be placed on roofs of buildings tops of constructions elements or towers. In rural areas, that kind of heliports may even be placed on trees, around mountings, bird observation or telecommunication towers. Remotely-located heliports need to be equipped with or connected to energy harvesting systems supplying enough power to charge service drones.

V. Scenarios

A. Encouraging for the Active Life

A person is having a passive style of life. The person is sitting in front of a computer and browsing the Internet. A personal drone takes off the nearby docking station and approaches the person.

The personal drone flies around the person, also – between a person's face and a computer screen and challenges the person to give up and get out of the chair. Finally, the person gets up.

The personal drone presents an idea for a set of physical exercises that would match the person the best. The person complains about pain in his arm. The personal drone updates the set of exercises. The communication is happening drone-to-person directly, or via smartphone, TV, or nearby screen used to control the Smart Home system.

Finally, the person starts exercising by being coached by the personal drone. The person warms-up by running along the corridor and back, following the drone, does squats, following the intensity set up by a personal drone flying up and down, and cools down by doing breathing exercises following the drone move. Finally, all the exercises completed, and the personal drone expresses happiness by making an excitement flight pattern in the air.

B. Hospital to a Person

A person waits for a liver transplant and now located far away from his home while travelling receives a message that an urgent extensive blood test must be done. A personal drone located in the transportation and charging container get on a blood test module equipped with the cooled container and gets out.

The personal drone flies to the person, lands on the arm, locates the vein using IR vision and takes the blood sample with the blood test module. When a blood sample is taken, cooling started to compensate for the weather temperature, and a needle is pooled inside the blood test module. The personal drone delivers the blood test module to the nearest service drone heliport and flies back to its transportation container. A service drone comes to the heliport and picks up the container. The container is delivered to the hospital by a chain of service robots performing delivery within their operating range from the heliport to heliport.

C. Outdoor Experiences

A person leaves home for hunting. On the top of the persons' rucksack, the docking station is attached. The docking station surface is made of solar cells. Four small wind turbines are located at four corners of the docking station. Both, solar cells and wind turbines are engaged in harvesting energy. A personal drone is firmly fixed on the docking station. At any time, the personal drone may take off the docking station and land back to it.

The personal drone takes off and flies autonomously or by a given direction to find animals. While the person is hunting, the personal drone follows the process at a distance and does video and photo records of hunting for a person's historical records.

The person experiences a problem with mobile connection due to geographical irregularities. The personal drone comes close and retranslates the signal to establish a strong connection. In case the connection quality is still poor, the personal drone calls a service drone. The service drone comes by and helps the personal drone to establish a good connection. When needed, the service drone may call other service drones, and the chain of drones helps.

The person finds that an important tool is forgotten at home. The personal drone flies back home, finds the tool and brings to the person. In case of a long way, it may get charged at any available heliport, or request a service drone to perform the delivery. The service drone comes to the person's home and interacts with a smart home system to get the requested tool. A butler drone brings the requested tool. The service drone delivers the tool to the person.

D. Road Accident

A person departure to work by car. A personal drone flies into a transportation and charging container located underneath the car. The car heavily crashes aside a road where traffic is very rare.

The car speaks to the person and finds that the person does not respond. The most probably, the person is unconscious. The car calls the emergency service.

The personal drone flies out of the transportation container. In case of a very heavy crash, the transportation container is dropped out of the car, and the drone gets out of the container from any side of it.

The personal drone flies around the crash area and scans it. A 3D image of the crash area is formed as a result. Police and insurance can use the image. In case of fire, the personal drone calls the fire department, uses the fire extinguisher located in the transportation container and calls service drones to help with fighting against fire.

The personal drone interacts with the car. The car opens the window, and the drone gets inside. Both, the car and the drone use their sensors to examine the health status of the person, e.g. pressure and heart rate. The personal drone sits on the person and takes the blood test with its fast blood test analyse module. The drone and the car exchange data and send it to the emergency service. Emergency services are aware of the preconditions of the person in advance, and therefore able to act more efficiently.

In the case when the car cannot reach the communication network or lost its power, the personal drone makes all the possible examination itself and gets at a higher altitude to transfer data if needed. Also, when needed, the personal drone engages a service drone to transfer gathered data.

VI. Conclusion

The development of both, Personal Drone and Service Drone concepts is still a work in progress. Even though drone technologies are in considerable advance these days, they are not mature enough to ensure a solid ground for the concepts to be implemented and widely adopted. The future development of state-of-the-art will advance technology enablers to be mature enough.

Among the technological restrictions are relevant to the small operating time of drones (battery life is too short for long-time missions and too much affected by weather conditions), communication and navigation limitations, computing capacity, AI, data processing and sensor technologies challenges, high cost of sophisticated body materials, main construction and moving parts, limitations of control interfaces, low efficiency and complexity of implementation of energy harvesting technologies, absence of supportive ICT infrastructure, low maturity of charging and heliport solutions, infancy of autonomous drone operations.

Among the organisational shortcomings are small business demand (due to high investment and slow return on investment), unclear and non-seamless integration into business processes and supply chain, a lack of qualified personnel, confused and changing policies and legislation and even prohibitions enforced by the last.

Among the operational limitations are human factors, process-relevant challenges, weather conditions, lack of supply and supportive infrastructure.

A collection of implicit or indirect challenges includes the following [35]. Negative psychological and physiological human responses to drones still require more detailed research. Heightened privacy considerations including data protection, concerning both, the society members and drone operators, are a subject for the general public and policymakers. Avoidance of erosion of human rights is to be considered at the entire process of drone operations from the planning stages to the mission outcome processing. Coordination with professional operations (e.g. rescue) is required for harm and hampering free missions. Consulting existing guidelines and professional codes of practice should be essential for all the stakeholders and actors of UAVs' operations. [35].

A combination of all, the cutting-edge state-of-the-art, positive user perception, supportive legislation and policies, will form a solid ground for implementing of Personal Drone and Service Drone concepts in the future.

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