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Multirotor UAV Design and Development – Case Study

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Abstract: This paper proposes the development and production of multirotor UAV parts using additive manufacturing. A new smart design approach is needed to take advantage of additive manufacturing in terms of reducing the product weight and making the product more customizable and specific purpose-oriented while also reducing the time and cost of product development and production. This paper provides a brief overview of three additive technologies: fused deposition modelling, stereolithography, and selective laser sintering. Two different UAV modules, the avionics module and GPS holder assembly, are described and produced. Also, some design ideas and approaches are explained, such as snap-fit joints and thread joints using hex bolt pockets and metal screws. The goal of this paper is to develop and manufacture special purpose UAV parts that are durable, sustainable, and low cost. For this purpose, the additive manufacturing process is proposed and described, from the idea to the final product.

Keywords: additive manufacturing; fused deposition modelling; multirotor UAV; selective laser sintering; stereolithography

1 INTRODUCTION

Unmanned aerial vehicles (UAVs) are used in various branches of civil and military operations mostly because of their versatility and low cost [1]. Three main reasons why UAVs are more applicable in some kind of missions than piloted vehicles are: a) absence of a pilot, b) simpler design due to the no need for life support systems like temperature, pressure, and oxygen control, c) simpler and cheaper production [2]. UAV multirotors are getting more popular for use in various kinds of missions that can be dull, dirty, or dangerous for human pilots [3–5]. Despite the relatively short range and flight time, multirotor UAVs find good use in applications like video and photo capturing [1], surveillance [3], crop inspection [1], fire detection [1], agricultural crop control [6], disaster monitoring [4–6], item delivery [1], robotics and education [7], military missions [8], even space missions [9]. Some of the advantages of UAV multirotors are vertical take-off, versatile design, ability to hover [1, 2].

When it comes to multirotors, their design is often not overly complex. However, because of UAV's rapid development, product development engineers need cheap and fast production technologies for rapid prototyping and fast product development [10]. Additive manufacturing allows quick testing of new designs in real life and has widely contributed to the fast development of multirotor UAVs [11]. In addition to being reliable, multirotors must also be lightweight, configured for specific purposes (specialized), and often of unconventional design to achieve longer flight times [12]. Additive manufacturing technologies offer valuable tools for UAV development and production [3–5]. Multirotor UAVs can come in different configurations regarding the number of rotors (propellers) [7]. The most common multirotor configurations are with four [13, 14], six [7], or eight [7] rotors, as shown in Fig. 1. Furthermore, UAVs can have tilted rotors that enable fully actuated control therefore, such configurations can move in a horizontal plane without tilting [7]. Due to the simplicity of design and straightforward operation, there is an enormous growth of multirotors in the market [1]. They can be controlled remotely or fly autonomously.

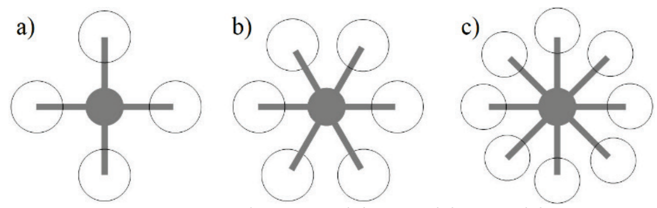

Figure 1 Multirotor configurations: a) 4 rotors, b) 6 rotors, c) 8 rotors

Multirotor parts are exposed to many different kinds of loads, thrust forces of propellers, wind forces, impacts, and weight of mounted objects [1]. Different multirotor modules must be designed in such way that it ensures structural stability under static and dynamic loads. Regarding the mechanical properties of 3D printed multirotor parts, several parameters to be considered, but the most important ones are the 3D printing direction and the orientation of object during printing [1]. In the design and development of multirotors amongst other production techniques, additive technologies often find very good use [6, 15]. Rapid prototyping technologies are also suitable for the production of special purpose multirotors as this type of aircraft usually requires individual production or the production of only a few aircraft [8, 16]. One of the most popular additive manufacturing technologies is Fused Deposition Modelling (FDM) due to its simplicity and low cost [1]. In addition, Selective Laser Sintering (SLS) and Stereolithography (SLA), can also be used for the production and development of UAV parts [17, 18].

Additive manufacturing can offer a new approach to design which can lead to innovative designs and also cut the time of the process from idea to final product [18, 19]. By shortening the time for the development of parts or whole products, the costs of the product can be reduced significantly [20]. Therefore, additive technologies are increasingly used for the development and production of UAVs [11]. In this work test parts for UAV multirotor have been designed and developed for additive manufacturing. Additive manufacturing technologies are used to produce several multirotor parts. The only parts not produced with additive manufacturing technologies are prefabricated low-cost standardized carbon fibre tubes, bolts, screws, propellers, motors, batteries, and onboard electronics. All multirotor parts produced by additive manufacturing can easily be scaled, resized, modified, and customized by adding features, holes, and slots for electronic parts.

2 ADDITIVE MANUFACTURING

Additive manufacturing (AM) processes are useful for rapid prototyping and product development, particularly for UAVs [11, 15]. The use of additive technologies can cut the development time significantly which reduces the costs and the price of the final product as well [11, 16]. The time required to get from the developer's idea to the finished product is reduced since it is possible to produce test parts faster with AM than using conventional manufacturing technologies which often include additional costs for tooling, moulding, machining, and other [17,21]. Also, AM allows the production of parts directly from a solid CAD model [11, 17]. Today, AM is commonly used to produce UAV parts and users can easily produce UAV replacement parts on low-budget 3D printers available on the market [9]. Thus, in the case of damage or breakage of individual parts due to the crash of the UAV, AM is suitable for the production of spare parts, which may include even propellers [18]. Additive manufacturing is a broad term that encompasses multiple additive manufacturing technologies [19–21]. Commonly used additive manufacturing technologies are:

- FDM – Fused Deposition Modelling,
- SLS – Selective Laser Sintering,
- SLA – Stereolithography.

There is a wide range of materials used in 3D printing, from metals, composites, and ceramics to hard and soft polymers [22, 23]. These softer materials are suitable for "soft robotics". Robots are usually constructed from hard materials like metal and hard plastics. To create parts of the robot that are more like soft materials found in nature, like skin and muscles, materials like rubber, hydrogels, and silicones are used. Additive technologies give us a possibility to produce parts with these softer materials which have Young's modulus around 10^4–10^9 Pa [23].

2.1 Fused Deposition Modelling

FDM (Fused Deposition Modelling) is manufacturing technology where objects are created by extruding a thermoplastic filament through a heated nozzle [6]. The whole process starts with creating a 3D CAD model and exporting it into an STL format [22]. The model is then cut into horizontal slices in the CAM software [17]. Nozzle paths are calculated by the software according to parameters set by the user. In this technique, the polymer filaments are fed to an extruder and then deposited on a platform through a nozzle moving in the XY plane, layer by layer [24]. Semi-melted thermoplastic material is pushed through a nozzle to be merged with the material from the previous layer on the part. When one layer is done, the entire platform will move vertically and apply a new layer to the previous one. Part is being built from the bottom to the top by moving the nozzle in the XY plane and by moving the platform in Z-direction [25]. Slices are usually thick between 0.1 mm and 0.3 mm [11]. Fig. 2 shows a working mechanism of the FDM process.

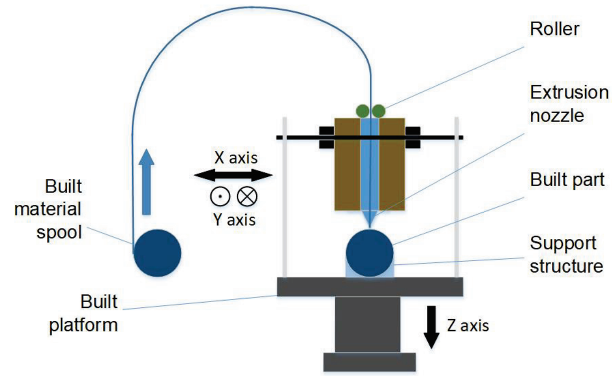

Figure 2 FMD working mechanism [1]

Various parameters can be set in the FDM process, such as layer thickness and height, number of shells (number of layers in the outer wall), infill percentage and geometry, built platform temperature, nozzle temperature and extrusion speed [1, 9]. These parameters are set in machine software after loading and positioning the STL file. The software then generates all the trajectories of the machine axes, extrusion speed, temperature, and behaviour of the machine according to the parameters set by the user [26]. Most common materials used in FDM are ABS (Acrylonitrile Butadiene Styrene), PLA (Polylactic Acid), PC (Polycarbonate), ASA (Acrylic Styrene Acrylonitrile), PPSF/PPSU (Polyphenylsulfone), ULTEM (trade name for a PEI (polyetherimide) variant), PE-HD/PH-HD (High-density Polyethylene), PE-LD (Low-density Polyethylene), PET (Polyethylene Terephthalate), and others [1, 11]. Also, it's possible to use composite materials in the FDM process [15, 27]. On the market, FDM 3D printers are available from low-cost desktop printers to more expensive industrial machines [1].

2.2 Selective Laser Sintering

SLS (Selective Laser Sintering) is a technology more suitable for industrial applications than other 3D printing methods [18]. SLS building material is available in powder form which is sintered using lasers to create the desired geometry [6, 28]. The powder is fed to the building chamber using rollers and piston and then is very accurately fused using laser beams [28]. This process does not require a support structure, since the unsintered powder provides the support for the object in the making [1]. With SLS is possible to make more complex plastic, metal, and ceramic parts that do not require a support structure [28]. Depending on the building material, the power of the laser system varies. To achieve certain mechanical properties of finish quality, further processing of part is needed, such as machining and/or heat treatment or coating [28]. Fig. 3 is showing the working mechanism of SLS.

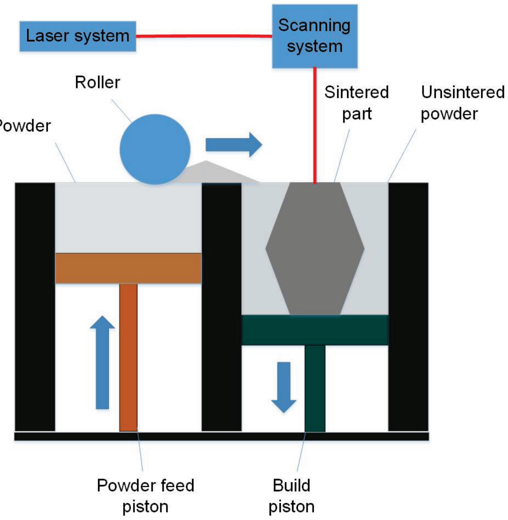

Figure 3 SLS working mechanism [1]

2.3 Stereolithography

Stereolithography (SLA) is an AM process in which objects are created by curing a polymer resin, using a UV laser beam in certain coordinates, layer by layer respectfully to the CAD model [6]. When one layer is cured by the laser, the built platform moves in the Z-direction and the new layer can be cured [28]. Materials for SLA are liquid form photosensitive thermoset polymers. With this procedure, it is possible to achieve high accuracy and smooth surface and it is the most cost-effective AM technology [6, 28]. In SLA laser is being focused with the mirror scanning system that cures the polymer resin with very high accuracy, which creates a smooth surface of the built object [1, 28]. However, SLA parts do not have particularly good mechanical properties compared to other AM technologies, so the use of SLA for UAVs is limited for the structural parts of the UAV, but it is very useful for rapid prototyping and development [1]. SLA is the first AM technology developed in 1986 by 3D Systems and it is first commercially available AM technology [6, 28]. Fig. 4 shows a working mechanism of the SLA process.

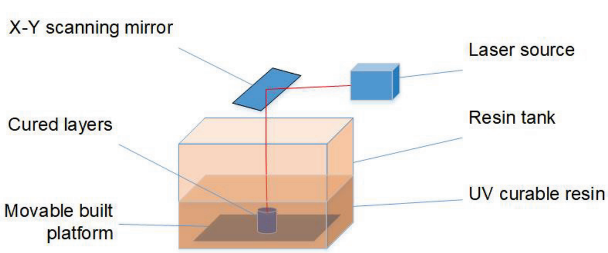

Figure 4 SLA working mechanism [1]

3 UAV DESINGN PROCES FOR ADDITIVE MANUFACTURING

AM technologies have certain advantages over conventional manufacturing technologies regarding design and production [17]. AM enables a new approach to 3D design without restrictions of conventional production techniques. Regarding manufacturing, AM offers low-cost production for smaller series without costs of tooling, moulding and machining [11]. In 3D design for AM, certain elements of the part need to be considered, such as requirements and use of 3D printed parts [29]. Engineers should take into consideration the thickness of the part, infill density and possibly add ribs and profiles for reinforcements [1, 9]. AM works very well in combination with low-cost standardized parts like screws and bolts for tight joints. For example, instead of 3D modelling and printing of threads, a hexagon pocket is made in part with the metal bolt to get a quality thread joint [30]. This kind of joint is commonly used in additive manufactured products because it's simplicity and low cost, as shown in Fig. 5. Another type of joint to be considered is the "snap-fit" joint, where one part fits and snaps to another creating a tight joint until physically separated, which is shown in Fig. 6 [19].

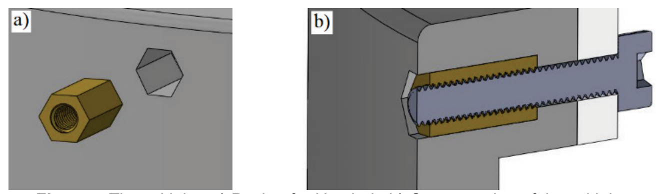

Figure 5 Thread joint: a) Pocket for Hex bolt, b) Cross-section of thread joint

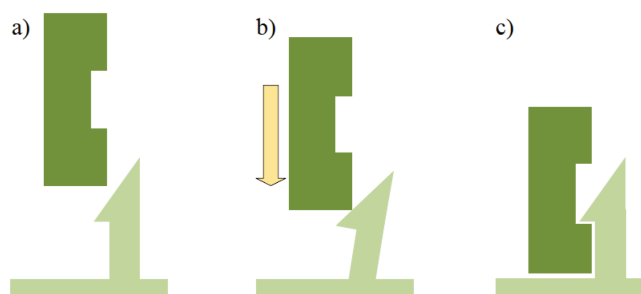

Figure 6 Snap-Fit Joint: a) separated, b) joining process, c) assembled

Snap-fit joints give the possibility to eliminate the use of screws and bolts which can decrease the mass of UAVs and enable easier and faster assembly and disassembly [18, 19]. Very few design instructions and guidelines of 3D design for AM have been published so the process of design can be a challenge, but with the liberty of layer-by-layer production, the 3D design process can result in very innovative designs and solutions [29, 31]. Another thing to consider is machine parameters set by the user in machine software. User can define the number of shells which means a number of outer solid layers of solid material, and infill density which affects the mass and mechanical properties of the product [6, 22]. There are many different infill patterns possible to use which also affect the mechanical properties of the product. Different infill patterns are used to achieve high-strength and low-weight structures for UAV parts. Also using different infill patterns can improve material usage efficiency [29, 32, 33]. Fig. 7 shows some of the possible infill patterns in 3D printing.

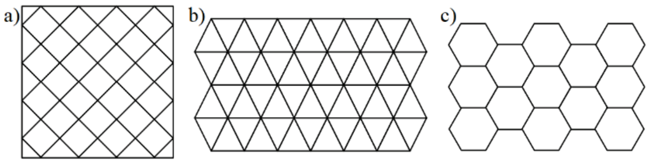

Figure 7 Infill patterns: a) square, b) triangle, c) honeycomb

User can also define parameters of the printing process such as printing bed and nozzle temperature, printing speed, support material usage and more [15, 17]. Fig. 8 is showing the entire process from the idea to the final product.

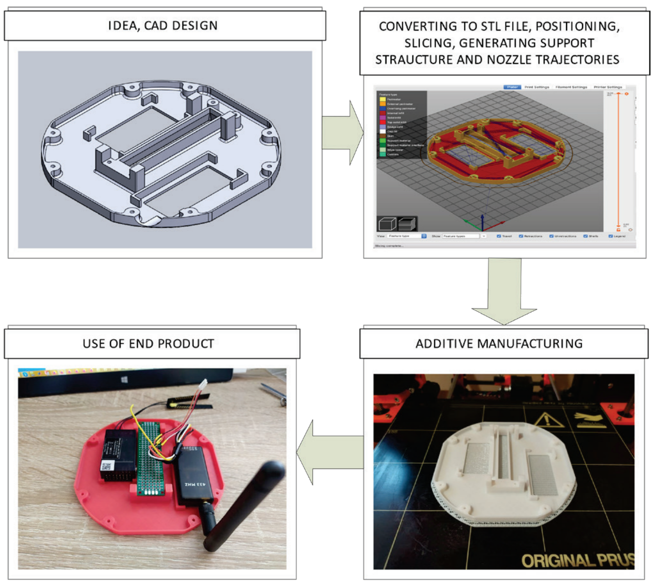

Figure 8 From idea to final product

There are a few requirements for the UAV test parts: structures should be lightweight, durable, and have a modular design (UAV systems and subsystems) [29]. Multirotors today are built mostly using conventional production technologies like injection moulding for plastic parts and using sheet materials cut into the desired shape. For smaller series, personalized products, and special purpose UAVs, AM technologies are more suitable if desired requirements are met [19]. Lightweight carbon fibre parts have good mechanical properties, therefore, are practical to use in combination with 3D printed parts for UAV assemblies [20].

4 DEVELOPMENT OF MULTIROTOR UAV MODULES

UAV consists of several systems and sub-systems or modules. The final assembly is divided into smaller modules some of which are: avionics, propulsion system, and electronics. All these modules work together in the final assembly as a harmonious system. The following section will detail components for two different UAV sub-systems fabricated using FDM additive technology.

4.1 Avionics

The avionics module housing provides housing and support for the electronics of the UAV. AM allow a specific housing design to fit specific electronic components particular for this UAV version. As this part of UAV will not be subjected to any mechanical load during use and the surface quality is not critical factor for functionality, the layer thickness was only considered for achieving satisfactory dimensional accuracy to ensure tight fit during electronic components assembly, resulting in a layer thickness of 0.2 mm. The infill pattern used for housing is also not critical factor since relatively thin walls require little or no infill making any infill pattern sufficient. The material used was PET-G, which provides high UV resistance and some flexibility before breaking, enabling it to handle tight fits during electronic component assembly. Fig. 9 shows the assembly model of the avionics housing part with visible openings and pockets designed to fit electronic components and to provide rigid and non-movable support. Assembly has two parts which are connected by screws and hex bolts. Inside of housing are 3D shapes that hold electronic parts and cables securely in place. The production time for all the parts related to this avionics module housing was approximately 4.5 hours.

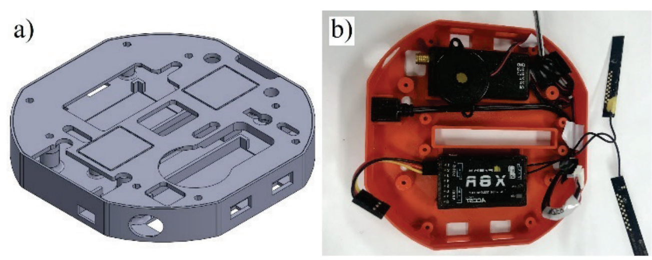

Figure 9 Avionics housing module: a) CAD model, b) 3D printed assembly

4.2 Foldable GPS Holder

3D CAD models and 3D printed GPS holder parts are shown in Fig. 10. The base part is connected to the avionics module by screw and bolt joints. Screws and bolts are also used to connect the rotary joint. Due to the rotary joint, the GPS holder can be folded when not in use. To ensure good mechanical properties, high dimensional accuracy, and smooth operation of holder folding and sliding of locking brackets, a layer thickness was 0.01 mm. The rods are printed using honeycomb infill to ensure required strength and lightness. To achieve good strength and sliding properties together with UV resistance, Nylon was chosen as the printing material. Furthermore, it is crucial to determine the correct orientation of the part on the printing bed to achieve desired mechanical properties. The strength will be improved in planes parallel to the printing bed, and the best sliding properties are achieved in the direction along the printed thread. The time required to fabricate all the parts necessary for the foldable GPS holder was approximately 7 hours. Low-cost additive technology allows more iterations of printing and design which is often the product development process when using AM. The GPS module can fit perfectly into the holder because it is 3D designed especially for this GPS element and produced with low-cost FDM additive technology. All parts are designed especially for use on this

UAV and can be modified and produced with any AM technology with low production and development costs.

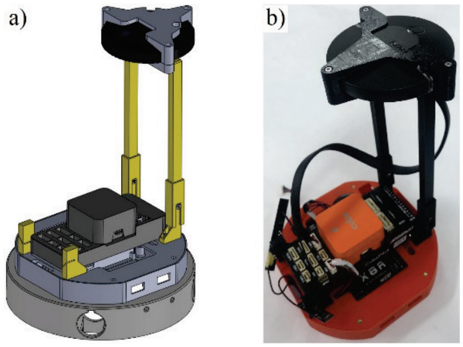

Figure 10 GPS holder: a) CAD model, b) 3D printed assembly

5 CONCLUSION

Additive technologies offer new possibilities in the manufacturing and rapid prototyping of products. New approaches in design for AM enable the faster creation of lighter UAVs that are easy to assemble. That is desirable for product development and design of UAV parts using trial and error methods.

The paper discusses various low-cost and effective joint techniques commonly used in 3D printing and some solutions for part reinforcement. These options are presented to overview the options available in the 3D printing world. The paper lists the materials and printing parameters utilized to fabricate the showcased UAV parts (avionics housing and foldable GPS holder). However, the determination of the appropriate material, adjustment of printing parameters required to achieve successful printing, desired dimensional accuracy, and mechanical properties of the parts, are not further discussed and are beyond the scope of this paper. For future work, other AM procedures will be conducted using different build materials and parameters. 3D printing of composite materials could offer better mechanical properties of parts and with little or no increase in mass, especially with different approaches in the design of UAVs.

The use of AM in the production and development of UAVs is an addition to advances in electronics and materials science which widely contribute to the growing use of UAVs in different fields of applications. AM is not only useful in rapid prototyping but also for the production of specific parts and small series of UAVs. Using AM engineers have the ability to create complex geometries without using expensive traditional technologies, tooling and machining, which is especially useful for the production of UAV parts that are mostly in small series and very specific from product to product. Thanks to AM, the production of parts has moved from factories to office desktops, homes, and development departments, resulting in the rapid development of UAVs.

Acknowledgements

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