Investigation of shielding materials impact on the effectiveness of UAV FSO communication systems

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Abstract. The use of Free Space Optics (FSO) for Unmanned Aerial Vehicle (UAV) communication is a relatively new innovation that could become a necessity for all scenarios where real-time delivery of high daterates is essential. The present paper investigates one of the challenges being faced by this type of system, in particular the relationship between shielding materials of the protective dome and the wavelength of the emitted photons.

Introduction

During the last years, UAVs have become an important part of national security. This kind of aircraft has proven to be tremendously flexibleand can be used for a number of civil and military tasks[1]. Telecommunications play a greater role in the operation of UAVs than they do for manned aircraft since all the decision-making occurs on the ground (either before or during the flight). Currently, communications between UAVs and ground stations are based on RF systems and low-earth-orbiting satellite links. Both are long range communications but also have low bandwidth (usually in the order of hundreds of kbps or less). In order to improve the communication quality, the move to optical carrier frequencies is essential. This type of frequency offers a qualitative leap because it provides a shift from MHz to hundreds of thousands of GHz, lowering the signal divergence by five orders of magnitude. Lower divergence allows higher reception power and signal-to-noise ratio, enabling faster communications with lower bit-error-rates. It is also a more secure technique since the laser communication beam cannot be intercepted without being noticed, as interception leads to signal fading. Another big advantage is that this technology enables lower power consumption and smaller and lighter terminals, [2]-[4].

An FSO communication system consists of an optical transmitter, a receiver and an FSO link (Fig. 1)[5].Consequently, one of the crucial factorsdetermining UAV performance is the existence of reliable, high performance wirelesscommunication links.Optical links have a number of advantages over RF, including high data rates, improved security and many others. The performance of laser based optical systems is not affected by ElectromagneticInterference (EMI) and is not subject to interference as withtraditional wireless devices such as microwave or radiosystem[6]. On the other hand, in order to protect the system hardware from weather conditions, etc., the construction of a protective dome is necessary. To ensure that the communication performance is not degraded, one must study the effect of the dome presence on the emitted signal.

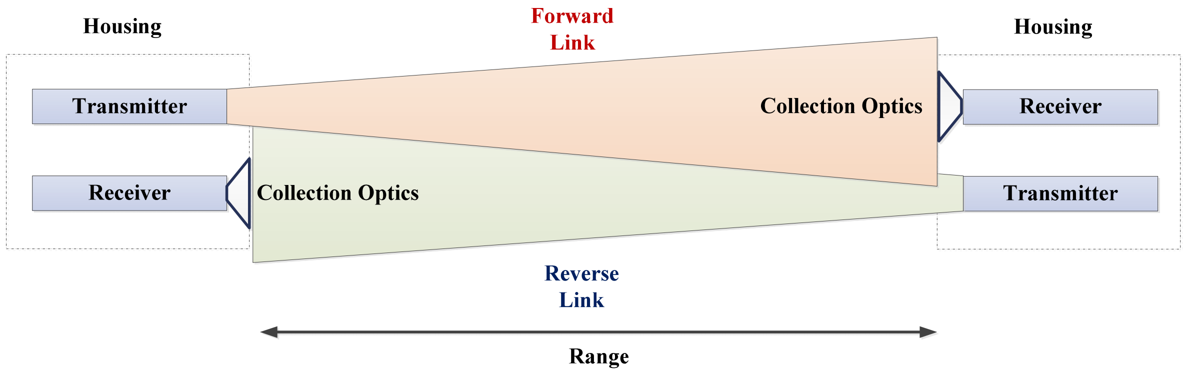

Fig. 1 FSO link[5].

The Use of Free-Space Optics by UAVs

Free-space optical communication can be made less susceptible to unwanted detection than radiofrequency communication because it is possible to concentrate an optical transmission in a narrow beam aimed towards the intended recipient. Hence, free-space optical transmission is an attractive option for covert communication between moving platforms, such as aircraft or ground vehicles. However, due to the fact that the optical beam is typically narrow, when the communicating parties are in rapid motion, it may be difficult to maintain a communication link for a significant time interval. Moreover, when an optical signal is transmitted through the atmosphere, atmospheric turbulence causes fluctuations in the amplitude and phase of the received wavefront, which can impair free-space optical links in much the same way that multipath fading affects radio-frequency wireless links.

Extensive research has been conducted on optical and electronic signal processing methods to overcome atmospheric turbulence, in links employing either coherent detection or direct detection [7]-[9]. Furthermore, J. Wang et. al.[10]have studied acquisition and tracking algorithms for free-space links between moving platforms, such as aircraft.

In addition, Unmanned Aerial Vehicles are increasingly being used for both civil and military operations and usually carry a large number of sensors for covering landscapes, border monitoring, observing traffic conditions on the roads, etc[6]. UAVs, particularly those flying in swarm formation, therefore require the acquisition of large amounts of data and thus a high rate of data connectivity.

Conventional communications between UAVs and ground stations mainly use RF or microwave systems and low-earth-orbiting satellite links. The data rates provided by such systems are in the order of hundreds of kbit/s or less. On the other hand, the use of optical carrier frequencies which is adopted by Free Space Optical Communication Systems can provide data rates exceeding several Gbit/s[11], [12].

A FSO communication system consists of an optical transmitter, a modulator and a telescope. The receiver consists of a detector, a decoder and a telescope to acquire the optical signal. Essentially, modulated optical beams are propagated through an atmospheric channel, in order to establish short, medium or long reach wireless data transmission. Furthermore the study of the special needs and requirements of the dome which covers the FSO unit on the UAV is also very important.

Currently FSO is being researched for applications involving ground-to-ground (short and long distanceterrestrial links), satellite uplink/downlink, inter-satellite, deep space probes to ground, ground-to-air/air-to-ground terminal [13]. Apart from offering higher data rates, other advantages include security aspects, low size and weight demands, small aperture sizes and low power consumption [14].

On the other hand for a FSO system to work, an unobstructed line-of-sight must exist. A potential weakness of such a set up therefore, is the susceptibility of FSO links to weather conditions. Fog in particular can cause severe attenuation of the propagated signal with even moderate continental fog resulting in attenuation of 130 dB/km [14]. The above issues must be therefore taken into account when using FSO for UAV applications.

Despite the great potential of FSO technology for UAV communications, little research has been performed concerning shielding materials of the protective dome and the wavelength of the emitted photons.

Materials used for electromagnetic interference shielding

Electromagnetic interference shielding refers to the reflection and/or adsorption of electromagnetic radiation by a material, which thereby acts as a shield against the penetration of the radiation through the shield[15]. Aselectromagnetic radiation, particularly that at high frequencies (e.g. radio waves, such as those emanating fromcellular phones) tend to interfere with electronics (e.g.computers), EMI shielding of both electronics and radiation source is extremely important for UAV communication systems. When defining the performance of a shielding material, the term often quoted is shielding effectiveness (EMSE). This value, obtained in decibels, provides an indication of thequality of shielding a material possesses[16].

Carbon materials are usually employed in EMI shielding and they include composite materials,colloidal graphite and flexible graphite[15]. Polymer-matrix composites containing conductive fillers are attractive for shielding [17] due to their processability(e.g. moldability), which helps to reduce or eliminate the seams in the housing that is the shield. Electrically conducting polymers are becoming increasingly available, but they are not common and tend to be poor in the processability and mechanical properties. Cement–matrix composites have higher shielding effectiveness than the corresponding polymer-matrix composites. Carbon is a superior matrix than polymers for shielding due to its conductivity, but carbon–matrix composites are expensive[18]. Metals are more attractive for shielding than carbons due to their higher conductivity, though carbons are attractive in their oxidation resistance and thermal stability. A particularly attractive EMI gasket material is flexiblegraphite, which is a flexible sheet made by compressing acollection of exfoliated graphite flakes without a binder.

Comparatively little research has been undertaken regarding new electromagnetic shielding materials in the past ten years [19]. Fibre reinforced polymer (FRP) composite materials have, however, been identified in recent years as being the desired choice for the replacement of orthodox metallic alloys in many aerospace applications [16].

FSO provides vastly improved electromagnetic interference behavior compared to using microwaves. On the other hand a material presents different characteristics during the propagation of light through it. The use of appropriate material for the dome construction can improve the efficiency of the FSO link. The absorption coefficient depends on the material and also on the wavelength of light which is being transmitted. The absorption coefficient determines the attenuation of light of a particular wavelength. In a material with a low absorption coefficient, light is only poorly absorbed, and if the material is thin enough, it will appear transparent to that wavelength.

Review of suitable materials

There is an increasing need for high-strength, robust materials which have the capability to transmit electromagnetic waves in the visible (0.4 – 0.7 micrometers) and mid-infrared (1 – 5 micrometers) regions of the spectrum. These materials are needed for applications requiring transparent protection, such as the case of a protective dome for a UAV FSO communication system. A review of suitable materials has led to the following[20]:

Polymeric Materials. Polycarbonate is the most common plastic used for transparent protection applications. It is a relatively cheap material that is easily manufactured, and offers excellent protection against small fragments. It is currently used in applications such as goggles, spectacles, visors, face shields and laser protection goggles, but is also used as a backing material for advanced threats. In the 1970s when these were first used it was found that their optical properties were not adequate for transparent applications. Since then, companieshave made improvements to the optical properties of the polyurethane providing more promising results.

Glasses and glass-ceramics. Several glasses are utilized in transparent protection, such as normal plate glass (soda-lime-silica), borosilicate glasses, and fused silica. Chemical or thermal treatments can increase the strength of glasses, and the controlled crystallization of certain glass systems can produce transparent glass-ceramics. The inherent advantages of glasses and glass-ceramics include having lower cost than most other ceramic materials, the ability to be produced in curved shapes, and the ability to be formed into large sheets.

Transparent crystalline ceramics. Transparent crystalline ceramics are normally used to defeat advanced threats. Three major transparent technologies exist currently: aluminumoxynitride (AlON), magnesium aluminate spinel (spinel), and single crystal aluminium oxide (sapphire). The incorporation of nitrogen into an aluminum oxide stabilizes a spinel phase, which due to its cubic crystal structure, is an isotropic material that can be produced as a transparent polycrystalline material. Polycrystalline materials can be produced in complex geometries using convention alceramic forming techniques such as pressing and slip casting.

Sapphire has been the material of choice for windows and domes where transparency from the visible to mid-wavelength infrared (MWIR) spectrum is required and where demanding optical, physical and environmental conditions exist. It is a high cost solution, and its an-isotropic mechanical properties make it difficult to fabricate. Furthermore, some applications require windows that are too large or shapes that are too complicated to be made from single crystal sapphire[21].

AluminumOxynitride (ALONTM Optical Ceramic) and Magnesium aluminate spinel are materials which have similar optical and mechanical properties to sapphire. Their crystal structure is cubic, so they are transparent in polycrystalline form. Consequently, they can be made by conventional powder processing techniques into near net shaped blanks as well as larger sizes and more complicated shapes than can be achieved with sapphire. Furthermore, their isotropic mechanical properties mean that they can be optically fabricated at a fraction of the cost of sapphire[21].

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