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Sensor design system and power adjustment of transmitter in FSO communication

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ABSTRACT

The main problem related to FSO communication is atmospheric attenuation. To cope with such problem and maintain a dedicated connection, the transmitter power has to be adjusted continuously depending upon the weather condition of that particular time. Here we propose a design where we utilize the precipitation detection sensor and visibility sensor of ASOS. The weather conditions are detected using these sensors and some statistical data collected over time. Each condition provides some set of rules and equations which interlinks the power of receiver and transmitter. The transmitter if operated on such equation would yield the maximum efficiency. This results in power saving of the model. An automatic power device for FSO could be designed. In the below-discussed idea, we strictly restrict ourselves on atmospheric attenuation domain. Other factors like pointing Loss, Free space loss, Divergence loss are not taken into consideration. To take these issues into consideration, calculations have to be complex. While designing a real model, these factors would be taken as an important factor of attenuation too. Here Noise Equivalent Power and transmission power equation have been proposed which has visibility as a variable.

Keywords— *Power, Attenuation, ASOS, FSO, Precipitation, Visibility, Atmosphere*

1. INTRODUCTION

FSO Signal communication system is one of the most futuristic and dynamic technologies. But due to high atmospheric attenuation caused due to Fog, Haze, Rain and Snowfall, it faces limitations like low propagation and data loss.

One of the main factors of developmental lag in hilly and border terrains of our country is the lack of proper communication. Regular Snowfalls and Foggy environment make it difficult for civilians, organizations, industries and defence sector to maintain a dedicated connection. Here FSO channels can be really helpful in providing quick and high bandwidth data. It also saves the cost incurred in wired communication Network. To main a continuous connection the transmitter should keep adjusting the power of transmission depending upon present weather conditions. Manual observation may turn unreliable in determining the power to cope attenuation. Here in this journal, we present an automated power determining system for FSO channels keeping in mind only the environmental attenuation. This method makes use of a few sensors (precipitation identifier and visibility sensor) of ASOS sensor Systems. Additional Temperature, humidity sensor (hygrometer) and water detector circuit are used. We analyze different cases of attenuation based on sensor report and statistical data and provide a Power requirement equation at various points of the day. The Transmitter can be programmed according to the equation we obtain.

The general equation for transmitter and receiver power is as follows:

$$P_{RX} = \frac{A_{RX}}{\pi\left(\frac{\theta}{2} * L\right)^2} * T * 10^{-\alpha\frac{L}{10}} * P_{TX} + P_{BG}$$

P_{RX}: Power of received signal
P_{TX}: Power transmitted signal,
A_{RX}: Receiver aperture area,
θ: Beam divergence angle,
T: Combined transmitter-receiver optical efficiency
P_{BG}: Optical power of background radiation,
L: Link range
α: Environmental attenuation in dB/km.

The first term in parenthesis is a geometrical attenuation due to beam spreading and is calculated for given parameters ARX, ϴ, and L as a ratio of aperture to signal beam cross-section. The atmospheric attenuation α is not a linear function of distance, it depends on many factors and changes randomly with time.

Total environmental attenuation *α(total)=Attenuation due to Fog (if present)+Attenuation due to Rain(if occurring)+Snow attenuation (if occurring)* or a combined effect of some or all of these.

1.1 FOG Formation Test and visibility calculation

Fog naturally occurs when high moist air cools downs due to a low temperature near the ground. It is common during the time near dawn and occurs very frequently during winters. We program our temperature sensor and relative humidity sensor to take readings at an interval of 2 hours between 12:00 noon and 12:00 midnight and at an interval of 1 hour between other 12 hrs span. Since the formation of fog is a gradual process, the following methodology would yield a fairly precise data.

The relative humidity sensor (hygrometers) hence takes 18 readings in 24hrs duration. It triggers the temperature sensor on when the reading is between 95% and 100% (because statistically, it is very difficult for the fog to form with less moisture content)

$$\text{Dew Point} = \frac{243.12 \times \left\{ \ln\left(\frac{RH}{100}\right) + \frac{17.62 \times T}{243.12 + T} \right\}}{17.62 - \left\{ \ln\left(\frac{RH}{100}\right) + \frac{17.62 \times T}{243.12 + T} \right\}}$$

RH: Relative Humidity
T: Temperature in Celsius

Now if the present temperature is less or equal to dew point temperature than a signal is sent to the ASOS sensor to calculate visibility

The attenuation due to fog is given by$= \frac{3.912}{V} \cdot \left(\frac{\lambda}{550}\right)^{-q} \; [dB/km]$. Where q has different values depending upon visibility (kruse model)

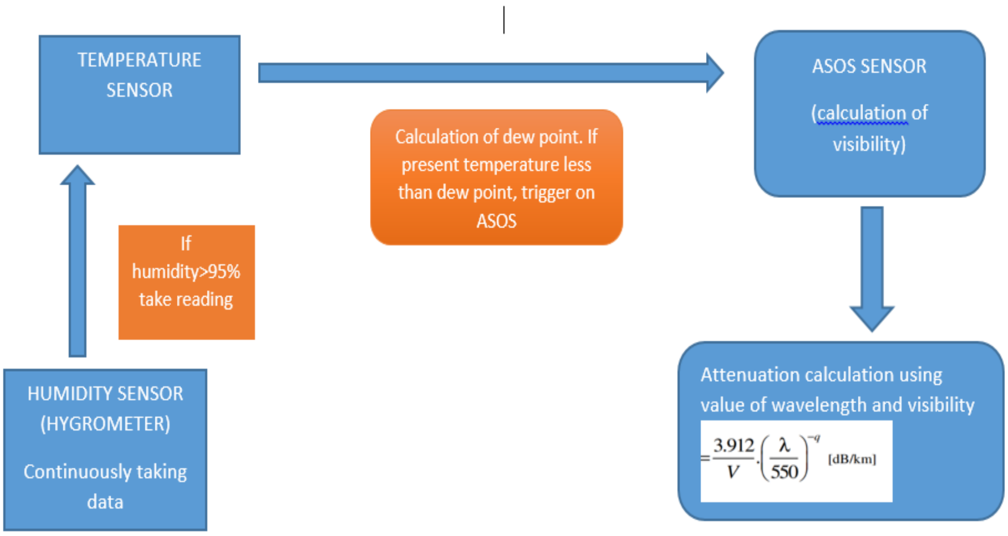

Fig. 1: Fog detection methodology

1.2 Dry Snow, Wet Snow and Rain detection

The first and foremost condition for any type of snowfall to occur is temperature. Low temperature serves as the ideal condition for snowfall. But snowfall occurs at a higher temperature too if humidity is abnormally low. The given statistics is the averaged result of recordings in various countries.

If the air temperature is less than or equal to -2 degree Celsius, then it is possible to have snowfall at any R. humidity. At -1 degree the R.humidity has to be less than 80%. At 0 degree the R.humidity must be less than 60%.and above 3-degree snow does not occur even at low humidity like 20%. Hence rainfall is the only precipitation thereafter.

We install a water detector circuit which sends a pulse if precipitation occurs. It serves two purposes: (i) It makes the temperature and humidity sensor to take values simultaneously and after that switch off because water can damage it. The sensor gets activated once again the water detector circuit has gone off and (ii) It sends a signal to the ASOS signal which starts calculating the visibility. The temperature sensor also provides the data. If the temp is above 2.7 degree Celsius it is rain else it is snowfall. Now the ASOS precipitation identifier is smart enough to distinguish between dry snowfall and wet Snowfall using Scintillation pattern when precipitate falls through the collimated infrared beam. Moist or wet ice has high melted water content. Due to adhesivity many snowflakes gets attached together providing it with a significantly large size.

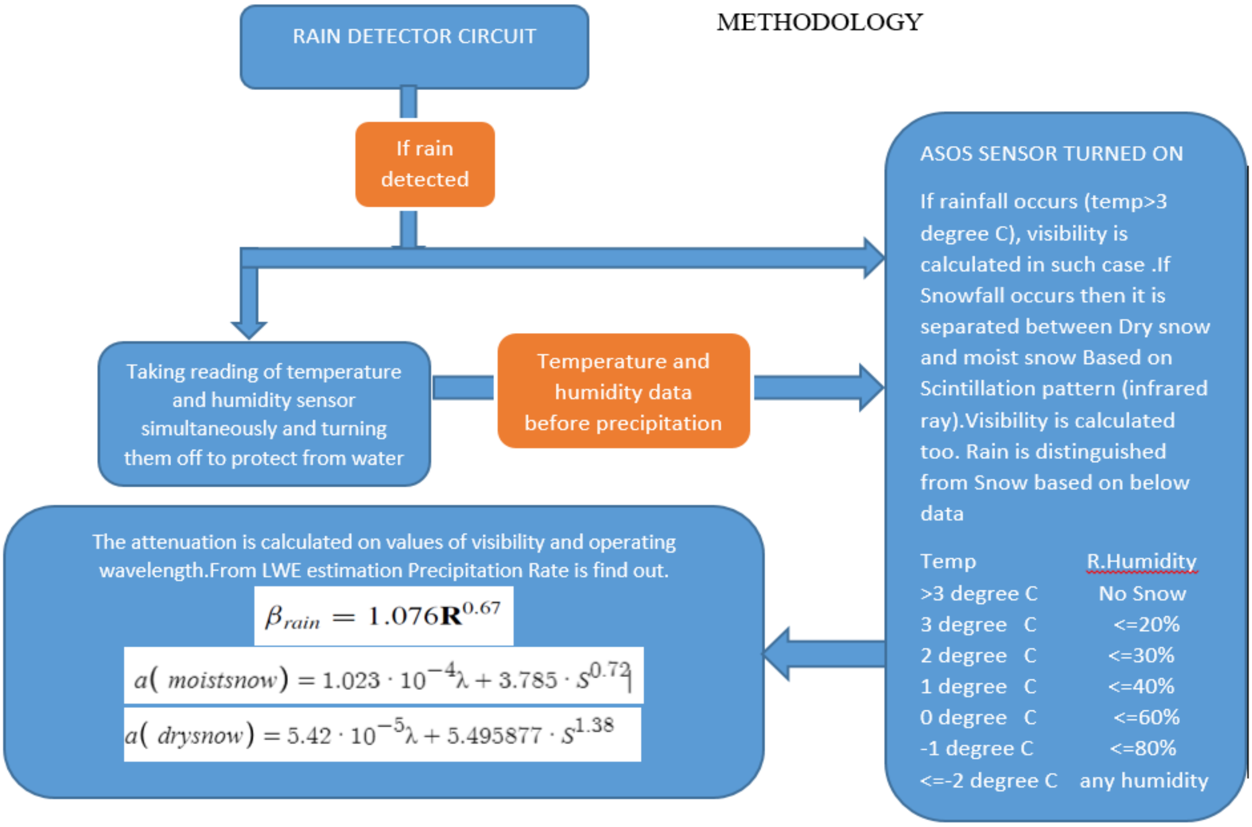

Fig. 2: Precipitation type and rate detection methodology

2. WORKING OF THE ASOS VISIBILITY SENSOR, PRECIPITATION TYPE DETECTOR AND ESTIMATION OF PRECIPITATION INTENSITY

Methods of estimating snowfall intensity are based either entirely or partially on atmospheric visibility. The U.S. National Weather Service manual estimates of snow intensity are determined by transmissometer estimates of visibility. Light snow intensity (−SN) is reported when the visibility is greater than or equal to 1.0 km, moderate snow intensity (SN) is reported when the visibility is less than 1km but greater than 0.5 km, and heavy snow intensity (+SN) occurs when the visibility is less than or equal to 0.5km (Data collected from National Weather Service 1994).

Automatic snowfall intensity measurements of Automated Surface Observing System (ASOS) are determined using a Light Emitting Diode Weather Indicator (LEDWI) system that automatically analyzes precipitation using the scintillation pattern produced by it as it falls through a collimated infrared beam. Snow intensity is determined by the 1-min-sum of low-frequency amplitude modulations due to snow. These snow intensities are adjusted, however, to be compatible with the visibility measured by the ASOS forward scatter visibility sensor Belfort 6220 according to the following rules.

1. If the LEDWI estimated intensity is light (−SN), no change is made.
2. If the LEDWI intensity is moderate (SN) or heavy (+SN) and the Belfort visibility is greater than 3/4 mi, the snowfall intensity is changed to light (−SN).
3. If the LEDWI intensity is heavy (+SN) and the Belfort visibility is greater than or equal to 1/2 mi, the intensity is changed to moderate (SN).

Source: Journal of Applied Meteorology; Volume 38:-Estimation of Snowfall Rate using Visibility by Roy M. Rasmussen, Jothiram Vivekanandan, and Jeffrey Cole(National Center for Atmospheric Research, Boulder, Colorado), Barry Myers (Transport Canada, Montreal, Quebec, Canada),Charles Masters (Federal Aviation Administration Hughes Technical Center, Atlantic City, New Jersey)]

Accurate data were taken substantially in the following years. The intensity of Snow or Drizzle based on the FMH-1 (2005).

Intensity	**Criteria**
Light	Visibility > 0.805 km
Moderate	0.805 km > Visibility > 0.402 km
Heavy	Visibility < 0.402 km

Many other experiments have been done in due course of time but here we carry on with our discussion taking these values only

3. COMPARISON OF ASOS AND LWE DATA VALUES

Now comes the role of Liquid Water Equipment (LWE) intensity statistics. An LWE instrument determines the amount of liquid present in falling precipitation from which a rate and an accumulation can then be calculated. The first successful experiment was carried out in the USA by using two gauges: (i): GEONOR in a Double Fenced Inter-comparison Reference (DFIR) shield and (ii):The Yankee Environmental Systems Inc. Hotplate. Snow pan data were collected every 10 minutes with one pan horizontal to the ground and a second pan inclined at a 10° angle from horizontal to simulate an airplane wing. Both pans were rotated into the prevailing wind direction at the beginning of each 10-minute observation. An LWE precipitation rate over the 10-minute observation period was calculated from the collected snow pan data. The visibility was recorded too. A graph showing the precipitation rate vs. Visibility. The experiment carried out Marshal Field Site and Denver International Airport yielded the following Threshold values

Intensity	**Threshold Criteria**
Light	1.0 mm/hr > Precip Rate > 0.4 mm/hr
Moderate	2.5 mm/hr > Precip Rate > 1.0 mm/hr
Heavy	Precip Rate > 2.5 mm/hr

Source- Comparison of precipitation rate intensities as determined by visibility versus liquid water equivalent measurements by Jennifer Black, Roy Rasmussen and Scott Landolt (National Center for Atmospheric Research, Boulder, Colorado)

The comparison gives an approximate precipitation rate range. To get more or less accurate data we rely on statistical data of that area. The local Meteorological office generally collects the precipitation rate monthly. Once our visibility is detected, it is compared with LWE statistics. The previous precipitation rates in the area, falling in the mentioned range are taken into consideration. For example, if the visibility is 0.5 km then the rainfall is moderate. The LWE stat shows that for moderate rain, intensity should be between 1mm/hr. and 2.5 mm/hr. So we analyze the previous rainfalls of that particular month to find out an intensity within the range. If there are multiple values, the average value is taken. We also can design a machine learning approach to estimate the precipitation Rate.

An approximate relation between Snow attenuation and visibility is $\propto_{snow} = \frac{58}{V}$

The same for Rain is $\propto_{rain} = \frac{2.8}{V}$

These formulae can also be used directly instead of calculating the precipitation rate.

4. POWER ADJUSTMENT/FLUCTUATIONS TO BE MADE

Generally, the FSO system runs on binary modulation format such as On-Off Keying (OOK) modulation. It has got high-power efficiency and simplicity. The electrical signal is converted to an optical signal by modulating the intensity of a laser source using the OOK modulation criteria. At the receiving end, a photodiode converts the optical intensities into the corresponding photocurrent. The PPM scheme modulation format is also used sometimes in FSO systems; it is more power efficient than OOK modulation but has less bandwidth efficiency, the demodulation is highly complicated too.

The power equation ignoring the optical power of background radiation is:

$$P_{RX} = \frac{A_{rx}}{\pi\left(\frac{\theta}{2} * L\right)^2} * T * 10^{-\alpha\frac{L}{10}} * P_{TX}$$

Our sensor technology tells us the type of weather condition. Now the following weather cases arise.

Fog attenuation case study: In fog attenuation, the power Received at the Receiver is a function of Visibility because the operating wavelength, range and other parameters like transmitting power, Transmitter efficiency, Divergence angle and Aperture is fixed(Adjusted once by controller manually).

Power received at the receiver is *Prx* and *Ptx* is the transmitted power

$$P_{rx} = \frac{A_{rx}}{\pi\left(\frac{\theta}{2}.L\right)^2}.T.10^{-\left(\frac{3.91}{V}\left(\frac{\lambda}{550}\right)^{-0.585.V^{0.33}}.\frac{L}{10}\right)}.P_{tx} \qquad \text{FOR V} < 6 \text{ Kms}$$

$$P_{rx} = \frac{A_{rx}}{\pi\left(\frac{\theta}{2}.L\right)^2}.T.10^{-\left(\frac{3.91}{V}\left(\frac{\lambda}{550}\right)^{-1.6}.\frac{L}{10}\right)}.P_{tx} \qquad \text{FOR V} > 50\text{kms}$$

$$P_{rx} = \frac{A_{rx}}{\pi\left(\frac{\theta}{2}.L\right)^2}.T.10^{-\left(\frac{3.91}{V}\left(\frac{\lambda}{550}\right)^{-1.3}.\frac{L}{10}\right)}.P_{tx} \qquad \text{FOR 6Kms} < \text{V} < 50\text{Kms}$$

Let us consider visibility is x km and x lies between 6 km and 50 kms. Let P_{tx} be power required to complete the Signal transmission process efficiently in case of no attenuation. By this we mean the message can be encoded properly at receiver. But due to fog getting, we are getting P_{rx} at receiver instead of P_{tx}. This may result in significant loss. (We chose the middlemost equation because of visibility criteria). Power Loss at receiver is *(P_{tx}-P_{rx})* or,

$$P_{tx}\left(1-\frac{A_{rx}}{\pi\left(\frac{\theta}{2}.L\right)^{2}}.T.10^{-\left(\frac{3.91}{V}\left(\frac{\lambda}{550}\right)^{-1.3}.\frac{L}{10}\right)}\right)$$

To compensate this loss, we have to send some additional power so that exactly P_{tx} reaches the receivers end.

So we separately perform a calculation. To get P_{tx}-P_{rx} at receiver we need to send P_{tx} (extra) at the transmitter be:

$$P_{tx}\left(1-\frac{A_{rx}}{\pi\left(\frac{\theta}{2}.L\right)^{2}}.T.10^{-\left(\frac{3.91}{V}\left(\frac{\lambda}{550}\right)^{-1.3}.\frac{L}{10}\right)}\right)=\frac{A_{rx}}{\pi\left(\frac{\theta}{2}.L\right)^{2}}.T.10^{-\left(\frac{3.91}{V}\left(\frac{\lambda}{550}\right)^{-1.3}.\frac{L}{10}\right)}.P_{tx}(extra)$$

$$P_{tx}(extra)=\frac{P_{tx}\left(1-\frac{A_{rx}}{\pi\left(\frac{\theta}{2}.L\right)^{2}}.T.10^{-\left(\frac{3.91}{V}\left(\frac{\lambda}{550}\right)^{-1.3}.\frac{L}{10}\right)}\right)}{\frac{A_{rx}}{\pi\left(\frac{\theta}{2}.L\right)^{2}}.T.10^{-\left(\frac{3.91}{V}\left(\frac{\lambda}{550}\right)^{-1.3}.\frac{L}{10}\right)}}$$

So Total power to be Sent: $P_{tot}=P_{tx}+P_{tx}(extra)$

$$P_{tot}=P_{tx}\left[1+\frac{\left(1-\frac{A_{rx}}{\pi\left(\frac{\theta}{2}.L\right)^{2}}.T.10^{-\left(\frac{3.91}{V}\left(\frac{\lambda}{550}\right)^{-1.3}.\frac{L}{10}\right)}\right)}{\frac{A_{rx}}{\pi\left(\frac{\theta}{2}.L\right)^{2}}.T.10^{-\left(\frac{3.91}{V}\left(\frac{\lambda}{550}\right)^{-1.3}.\frac{L}{10}\right)}}\right]$$

To be energy efficiency, P_{tx} should be just above the Minimum Detectable energy of the receiver. The receivers are photodiodes which convert signals into photocurrent. The Noise Equivalent Power (NEP) of a detector is the optical power incident to the detector that needs to be applied to equal the noise power from all sources in the detector; in other words, NEP is the optical power that results in an SNR of 1. Basically, this represents the threshold above which a signal can be detected. The minimum detectable power P_{min} can be easily calculated using the following formula:

$$P_{min}=NEP\ (\lambda)\times\sqrt{BW}$$

Here NEP (λ) is the wavelength-dependent NEP and BW is the measurement bandwidth.

$$NEP\ (\lambda)=NEP_{min}\times\frac{R_{max}}{R(\lambda)}$$

Here, NEP_{min} is the NEP as given in the specifications, R_{max} is the maximum responsivity of the detector, and $R(\lambda)$ is the responsivity of the detector at wavelength λ. R_{max} and R(λ) can be read from the detector responsivity curves that are provided in the Operating Manual. For a given detector, the lowest NEP is achieved at the wavelength with maximum detector responsivity. This value is Minimum NEP.

Source about NEP is from NEP: Noise Equivalent Power by Verena Mackowiak (GmbH), Jens Peupelmann (GmbH), Yi Ma (USA), and Anthony Gorges (USA) Thorlabs, Inc., 56 Sparta Avenue, Newton, NJ 07860, USA; Thorlabs GmbH, Hans-Bockler-Str. 6, 85221 Dachau, Germany

The Bandwidth and operating wavelength will be well known to us. P_{min} will be calculated easily. After the modifying transmitter power equation, P_{tx} is power received at the collector. Now

$$P_{tx}\geq NEP(min).\frac{Rmax}{R(\lambda)}.\sqrt{BW}$$

The coefficient of P_{tx} in the equation of total transmitter power P_{tot} is a positive quantity. So multiplying the coefficient of P_{tx} on both sides of the above equation gives

$$P_{tot}\geq NEP(min).\frac{Rmax}{R(\lambda)}.\sqrt{BW}*\left[1+\frac{\left(1-\frac{A_{rx}}{\pi\left(\frac{\theta}{2}.L\right)^{2}}.T.10^{-\left(\frac{3.91}{V}\left(\frac{\lambda}{550}\right)^{-1.3}.\frac{L}{10}\right)}\right)}{\frac{A_{rx}}{\pi\left(\frac{\theta}{2}.L\right)^{2}}.T.10^{-\left(\frac{3.91}{V}\left(\frac{\lambda}{550}\right)^{-1.3}.\frac{L}{10}\right)}}\right]$$

The Transmitter power varies according to the above equation in case of foggy weather. The above equation is a function of Visibility (and between 6kms and 50 km). The general equation in terms of α is.

$$P_{tot} \geq NEP(min).\frac{Rmax}{R(\lambda)}.\sqrt{BW} * \left[1 + \frac{\left(1 - \frac{A_{rx}}{\pi\left(\frac{\theta}{2}.L\right)^2}.T.10^{-\alpha.\frac{L}{10}}\right)}{\frac{A_{rx}}{\pi\left(\frac{\theta}{2}.L\right)^2}.T.10^{-\alpha.\frac{L}{10}}}\right]$$

Here α is attenuation and it has different values for wet snow moist snow rain etc. After the sensors detect each weather conditions, calculations are made likewise. This gives our power adjustment and signal flow becomes continuous and efficient.

Sometimes it happens that rainfall is accompanied by foggy weather. Such analysis becomes difficult and requires further modifications of algorithms. The visibility detected, in that case, is the combined result of a different kind of attenuation but our formulae deal with the relationship between visibility and attenuation or power in each specific attenuation case. This leaves the scope for further research of combined attenuation cases.

5. CONCLUSION

We hence propose a systematic approach to determining weather conditions. The attenuation is calculated and then transmitter power is calculated likewise. This is a dynamic system which regulates the power ensuring loss minimization and dedicated connectivity. The transmitter sends power according to the derived equation which has visibility as a variable. The approach uses both statistical data and real-time data in working. Although a power equation is derived, it only considers atmospheric attenuation. While designing a true model many other factors like pointing loss, beam divergence loss, free space loss and atmospheric turbulence has to be taken into consideration.

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