Assessment of Different Technologies for Improving Visibility during Foggy Weather in Mining and Transportation Sectors

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***Abstract*—** Generally during foggy weather in winter season, mining operation remains suspended for hours due to problem of visibility. Foggy weather also leads to accidents, loss of life and infrastructure damages in mining and transportation sectors. This paper discusses about the existing technologies for improving visibility in transportation sector and suitability assessment of these technologies in mines for uninterrupted mining operations in foggy weather.

Keywords- *Radar technology, GPS, Infrared thermography, Internet of Things, Robotics, Drone camera.*

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1. INTRODUCTION

In developing countries mining industry plays a major role for power generation and economic growth. Generally, during foggy weather in winter season, mining operations cannot be carried out during one-third of a day due to problem of visibility which reduces production rate of an opencast mine. Mining industry runs some of the heaviest machines and vehicles. While operating these machines and transportation vehicles in active and complex environment the operators are required to be aware of everything around them to avoid accidents and minimize damages. Therefore, it is a paramount importance for mining industry to improve visibility so that mining operation can be continued during foggy weather.

Every year during winter, railways and aviation sectors face huge monetary loses due to cancellation of services, delays and accidents. Fog is the major contributor towards these issues. Fog also causes accidents on roads as it is impossible to see long distance during foggy weather. The visibility was measured to be in the range of 50 m in New Delhi, India till mid of the day during winter due to fog [1].

Various researchers are investigating on radio detection and ranging (radar), global positioning system (GPS), infrared thermography, Internet of Things (IoT), robotics and other technologies to improve visibility of mining machinery operators [2]. These technologies provide more information about surrounding and assist in detection and avoidance of potential collisions. This paper briefly enumerates assessment of different technologies that can be used for safer operation in mines and public transportation.

2. RADAR TECHNOLOGY

Radar is an electronic device that detects an object at a certain distance by using powerful microwave energy. It is weather independent and covers large area.

2.1 Principle of Radar

Working principle of radar is similar to the principle of sound wave reflection. Radar uses electromagnetic pulse. This pulse frequency is transmitted from radar which is reflected back from the detecting object. This small amount of reflected pulse energy is received by radar and is called "echo". Radar uses this echo to determine direction, speed and distance of the object from radar base. Frequency of the used wave is unaffected by weather and darkness. Schematic diagram showing basic operating principle of radar is shown in Fig. 1.

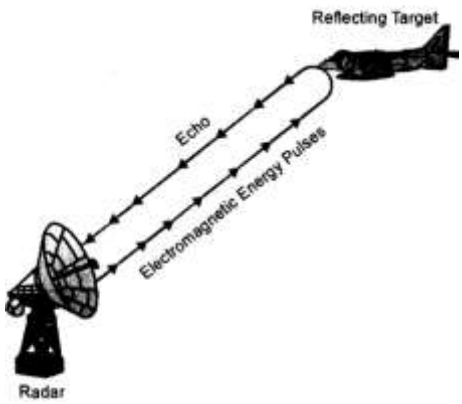

Fig. 1: Schematic diagram of radar operation [3]

Fig. 2 illustrates block diagram of basic operating circuit of radar. Radar antenna illuminates the target with a microwave signal (radar pulse) and the reflected microwave signal from the target is received by the receiver. A duplexer here acts like as a switch. It stops the transmitted signal from going into the receiver.

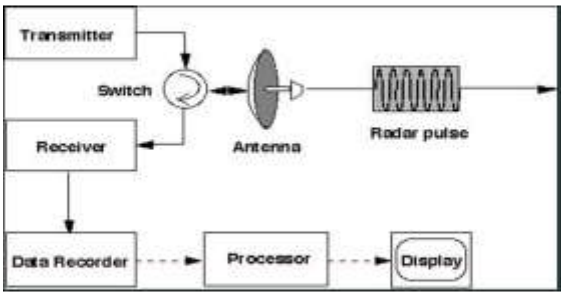

Fig. 2: Block diagram of radar circuit [4]

Radar signal is generated by a powerful transmitter which is received by a highly sensitive receiver. Block diagram of operating principle of radar is shown in Fig.3.

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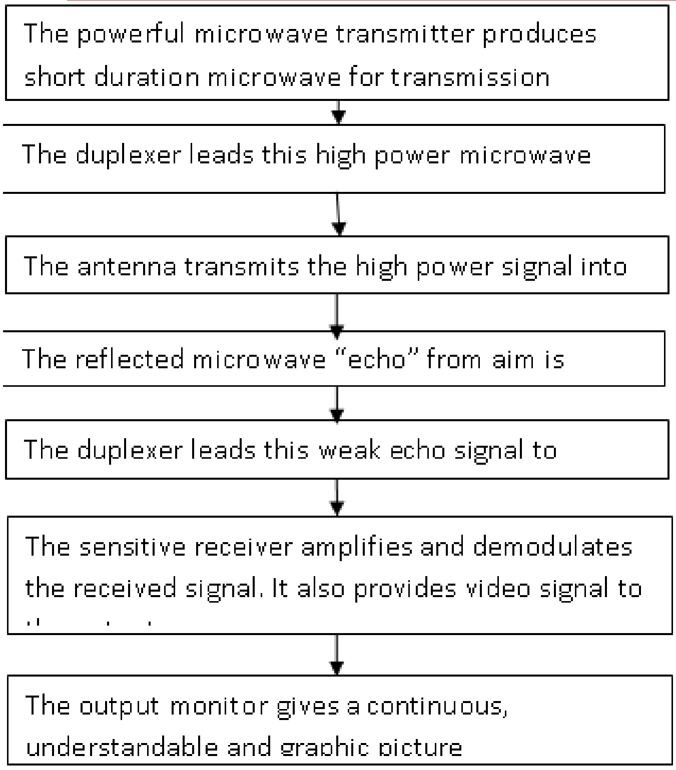

Fig. 3: Signal routing block diagram

2.2 Signal Routing in Radar

Functions of radar system are time dependent. Synchronization between receiver and transmitter is a very important aspect to determine range of the target. The transmitted pulse is sent by the antenna into space during transmission time. Radar waits for returning echo during rest time or receiving time, and then transmits the next pulse. Pulse repetition period or pulse repetition time (PRT) is the time between beginnings of one pulse to the next pulse (Fig. 4). It can be represented mathematically as [5]:

$$PRT = 1/PRF \qquad \text{Eq. (1)}$$

Where, PRF is called pulse repetition frequency. It is the number of pulses transmitted by radar per second.

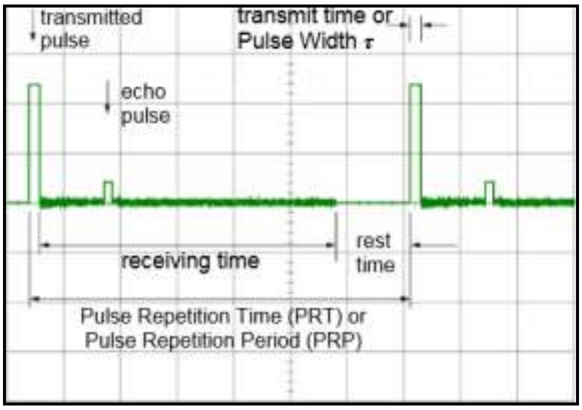

Fig. 4: Transmitter and receiver synchronization in basic radar [5]

2.3 Distance Determination

The actual range of a target from radar is called slant range. Slant range is line of sight distance between the radar and illuminated target. Since wave travels to and from the object, the time is divided by 2 to measure the time signal took to reach the object [5]. The mathematical formula for determination of range is given by:

$$R=c*(t/2) \qquad \text{Eq. (2)}$$

Where,

c = Speed of light (3×10^8 m/s),
t = Measured running time, and
R = Slant range of antenna.

2.4 Operating Frequencies

There are no fundamental limits on radar frequency. Any device that detects and locates target using microwave energy can be classified as radar irrespective of its frequency. Radar operates at frequencies from few megahertz to ultra violet region of spectrum. Basic principle is same at all frequencies but their practical implications are different. Table 1 indicates general frequency band at which radar operates. The remote sensing community uses letter (L) designation for frequency bands. These designations were used to keep radar frequency a secret during World War-II and afterwards. In 1959 at Geneva, International Telecommunication Union (ITU) standardized the letter bands representing radar frequencies. These letter bands are convenient way to designate general frequency of radar. Institute of Electrical and Electronics Engineer (IEEE) has been maintaining the letter designations for radar frequency bands since 1976. They serve an important purpose for military applications since they can describe the frequency band of operation without using the exact frequencies at which radar operates [6]. They serve an important purpose for military applications since they can describe the frequency band of operation without using the exact frequencies at which radar operates. According to ITU, radar is assigned specific frequency bands for its use. Each frequency band has its own particular characteristics that make it better for certain application than others [6].

Table 1: Frequency letter-band nomenclature of standard radar [7]

Band designation	Frequency range	Usage
High frequency (HF)	3–30 MHz	Over the horizon (OTH) surveillance
Very high frequency (VHF)	30–300 MHz	Very long range surveillance
Ultra high frequency (UHF)	300–1000 MHz	Very long range surveillance
L	1–2 GHz	Long range surveillance en-route traffic control
S	2–4 GHz	Moderate range surveillance terminal traffic control

C	4–8 GHz	Long range tracking air bone weather detection
X	8–12 GHz	Short range tracking, missile guidance, marine radar
K_u	12–18 GHz	High resolution mapping, satellite altimetry
K	18–27 GHz	Little use
K_a	27–40 GHz	Very high resolution mapping, airport surveillance
MILLIMETER	40–100 GHz or more	Experimental

2.5 Applications

Radar technology is currently being used in different fields varying from aviation to mining. The technology makes the working environment safe as it is generally unaffected by terrain and weather**.**

2.5.1 Mining

Close interactions between a shovel and other equipment, such as, dozers in the loading area results in an increased risk of metal-to-metal and machine-to-human contacts at large opencast mines [8]. It is desired to build a system that alerts the operator when another vehicle is in proximity of the shovel as shown in Fig. 5. Also limited visibility in the mining environment due to dust and in some countries fog in winter made it tougher for the operator of shovels and trucks to navigate thereby causing accidents. To overcome this problem companies are incorporating radar based systems in order to avoid collision of vehicles and thereby improving safety of miners and heavy equipment. M/s SAFEmine Technology Inc, USA is among the companies that have installed radars in heavy vehicles. The SAFEmine collision avoidance system (CAS) uses a vehicle-to-vehicle radio network and GPS to provide vehicle and equipment locations, and their identification numbers in an aerial view screen layout on a touch screen video display (Fig. 5). This shows the operator location of other equipment and gives an audible and visual reminder that a piece of equipment has entered into the swing radius of the shovel. Alarms and detection zones can be adapted according to vehicle type and the mine's operational parameters. Six tracking radar sensors are mounted on the shovel body to monitor close proximity of equipment and personnel. This high accuracy detection system provides a more intense warning to the shovel operator if another vehicle is within the shovel's body swing radius [8]. An indicator on the screen identifies the radar unit that has detected the vehicle or object (Fig. 5).

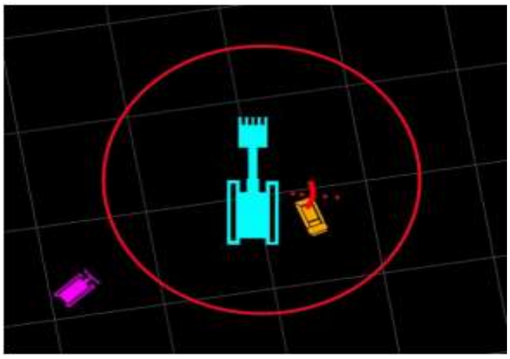

Fig. 5: Radar assisted aerial view of other vehicles position for a shovel [8]

Engineers at National Institute of Occupational Safety and Health (NIOSH) tested several proximity warning systems [9]. Caterpillar dumpers were selected in the test at NIOSH due to its severity of accidents and typical blind spots. During initial tests, a 50 ton capacity off highway truck was used. The proximity warning system was loaded at the rear of the truck. After placing the proximity warning system on the truck the entire set up was tested by backing the truck towards a stationary person or a pick up. The detection zone was recorded for each test object and later analyzed if the zone was sufficient enough to avoid collision.

The NIOSH came up with two radar systems, namely (i) Single antenna preview radar system and (ii) Double antenna preview radar system [9]. Fig. 6 shows the difference between single antenna preview radar and double antenna preview radar detection. Finally, it was observed in the test that double preview radar system was better than single preview radar system.

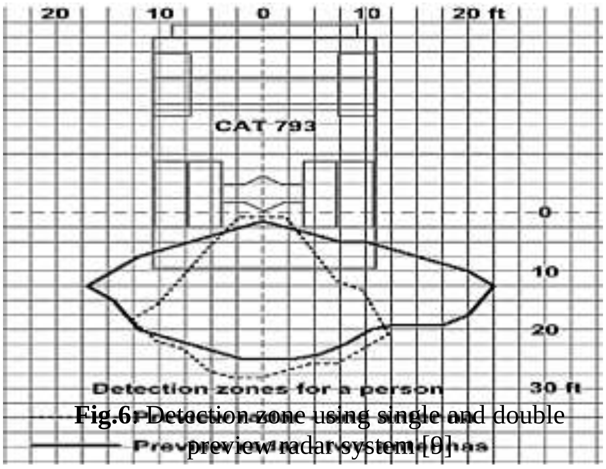

Fig.6: Detection zone using single and double preview radar system [9]

2.5.1.1 Single Antenna Preview Radar System

It uses pulse radar to sense presence of an object in the path of vehicle and on-board system gives both audible and visual warnings. A series of LED lights glow in succession and warning tone changes according to distance of the obstacle. This system is called preview radar system. Drawback of such system is that the radar can sense obstacle at a distance of 8.5 m but an obstacle cannot be detected near the rear tyres due to narrow beam patterns of the radar.

2.5.1.2 Double Antenna Preview Radar System

Using this radar entire area near the vehicle is covered. In this system two antennas are used for detection of any object in the vicinity of a vehicle. A single alarm is interfaced to both antennas and detection area near the vehicle is increased. Effective detection of person and smaller vehicle around the vehicle is observed which is better than single preview radar system.

The false alarm may be generated with obstacles already known to the driver which are not hazardous, like a small pothole or a small rock. For this reason, a video recorder that accepted sensor inputs was used to record time-stamped video from a rear-mounted camera, along with radar alarms. The camera view of the same area is made available to the driver (Fig. 7) so that the driver can judge the situation accordingly [10]. The combination of radar along with camera reduces inconvenience to the drivers since they don't have to climb down every time to check the origin of alarm. It also saves time. The camera covers the same area as the radar in the rear of the truck which helps the drivers to judge the rear of the truck without coming out of the truck.

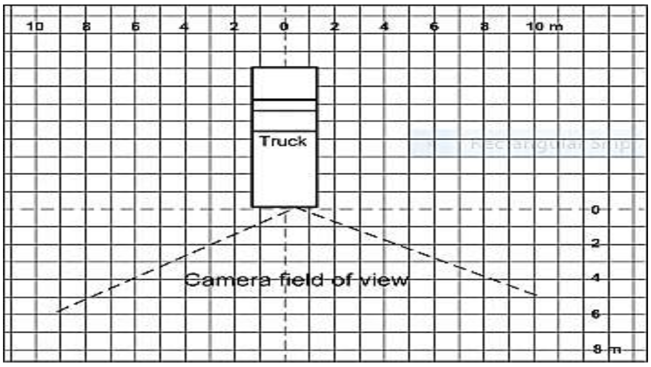

Fig. 7: Camera view mounted next to radar [10]

2.5.2 Aviation

Microwave landing system (MLS) was designed as advanced precision approach system that would overcome the disadvantages of conventional radar based landing system and also provides greater flexibility to its users. However, there are few MLS installations in use at present and they are likely to co-exist with existing landing system for a long time. MLS is a precision approach and landing system that provides position information and various grounds to air data. The position information is provided in a wide coverage sector and it is determined by an azimuth angle, elevation and range measurements [11].

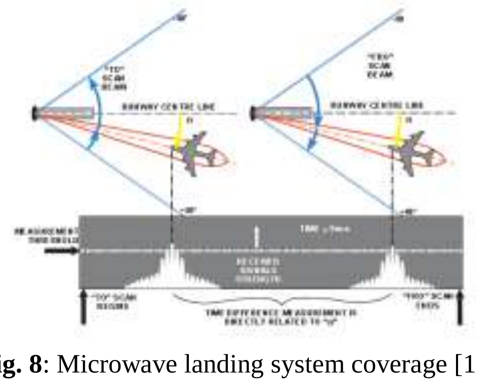

Fig. 8: Microwave landing system coverage [11]

MLS employs the principle of time division multiplexing (TDM) as shown in Fig. 8, whereby only one frequency is used on a channel but the transmissions from the various angles and data are synchronized to assure interference free operations on the common radio frequency for determining the object locations.

2.5.2.1 Azimuth Location

Time referenced scanning beam (TRSB) is utilized for determining azimuth and elevation of an object. The aircraft computes its azimuth position in relation to the runway center-line by measuring the time interval in microseconds between the receptions of 'to' and 'fro' scanning beams. The beam starts the 'to' sweep at one extremity of its total scan and travels at a uniform speed to the other extremity. It then starts its 'fro' scan back to its start position. The time interval between the receptions of 'to' and 'fro' pulses is proportional to the angular position of the aircraft in relation to the runway on-course line. The pilot can choose to fly the runway on-course line or an approach path which he/she selects as a pre-determined number of degrees as well as runway direction (Fig. 8).

2.5.2.1 Glide slope Location

Beam of microwave scans up and down at a uniform speed within its elevation limits. The aircraft's position in relation to its selected glide slope angle is thus calculated in the same manner by measuring the time difference between the reception of pulses from the up and down sweeps. Transmissions from the two beams and transmissions from the other components of the MLS system are transmitted at different intervals i.e. it uses 'time multiplexing' [11].

2.5.3 Railways

Object detection using radar technique is useful in detecting objects in foggy weather. Owing to dense fog the trains are delayed causing loss of revenue and inconvenience to passengers. It also causes accidents resulting in loss of life and loss of infrastructure to the government. Operating frequency range for radar system varies along with the variation of fog density (Chakraborty et al., 2010). Imaging technique by radar is used to detect object in path and its time of persistence. The longer the object persists in the line of movement the darker is its image. When there is no obstacle the image is white.

2.5.4 Road Transport

Road collision during foggy weather is a normal phenomenon in India. A need for collision avoidance system using radar technology was proposed by Dubey et al.(2013). A micro-controller based radar system receives echo signal from ultra-sonic range finder sensor (Fig. 9). This information is used to excite solenoid to create electromagnetic field. Ultrasonic sensor measures distance between the vehicle and detected object, which is displayed on the dashboard of a car. Once a car comes within certain range of another vehicle, the excitation circuit starts working to create electromagnetic field. This warns the car driver to avoid collision.[12]

ZigBee technology is providing a set of solutions for sensor and control systems. The physical layer accommodates the need for a low cost yet allowing for high levels of integration. The use of direct sequence allows the analog circuitry to be

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very simple and very tolerant towards inexpensive implementations. Once a car comes within certain range of another vehicle, the excitation circuit starts working to create electromagnetic field. This warns the driver and hence avoids collision [13].

The in system programming (ISP) or in circuit programming of a microcontroller refers to programming the microcontroller while it is in the target circuit. That means there is no need to remove the microcontroller from the device for reprogramming it. Rather the target has an ISP connector where the ISP programmer is connected.

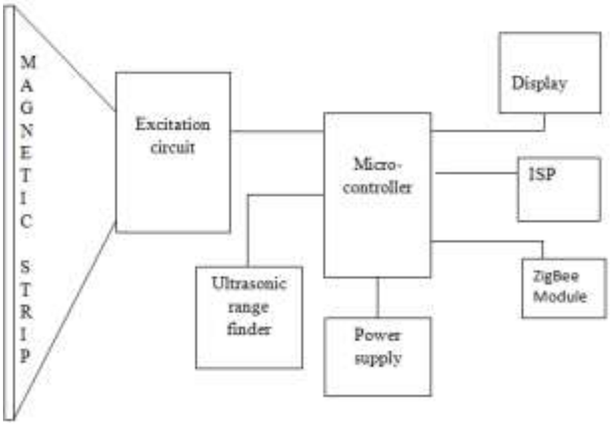

Fig. 9: Block diagram of anti-collision system [12]

3. GLOBAL POSITIONING SYSTEM

Global positioning system (GPS) was developed in 1973. It is a satellite based positioning system available 24 hours a day 365 days a year everywhere on the globe. It was originally designed for real-time positioning with metre-level accuracy for airplanes, ships, cars, missiles, etc. as depicted in Fig. 10.

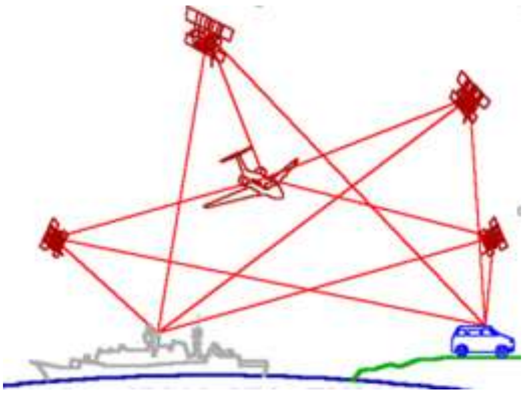

Fig. 10: GPS navigation system [14]

3.1 Operating Principle

GPS satellite orbit is 11000 miles from earth. The orbit and location of a satellite is known in advance. GPS receiver stores orbit information for all GPS satellite in an ALMANAC (14).It is a file that contains positional information of all GPS satellites. The GPS receiver can inform about its own position by comparing the data with three or more GPS satellite. Distance measurement from two satellites limit our position to the intersection of two spheres which is a circle. A third measurement limits the position to two points. A fourth measurement from a fourth satellite limits our position to a single point which is our true location as shown in Fig. 11. [14]

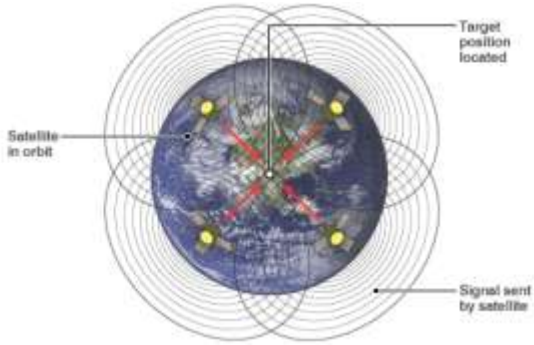

Fig.11: Schematic diagram of GPS operating principle[15]

3.2 Signal Routing

GPS signal routing consists of three segments, namely space segment, control segment and user segment [16] as illustrated in Fig. 12. Satellites are called space segment of GPS system. It broadcasts radio signal towards the user on the earth and receives commands from the ground. Control segment monitors the space segment and sends commands to satellite. The receiver in user segment receives record and interprets the radio signals broadcast by satellites.

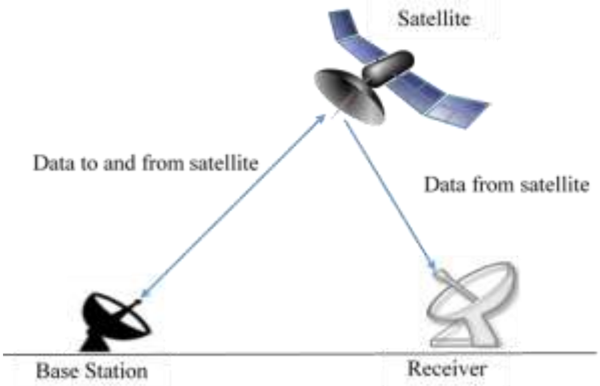

Fig. 12: Three segments of GPS [17]

3.3 Pseudo Range

Pseudo range is the virtual distance between a satellite and a navigation satellite receiver. To determine its position, a satellite navigation receiver determines the ranges from (at least) four satellites as well as their positions at the time of transmitting. Knowing the satellites' orbital parameters, these positions can be calculated for any point of time. Pseudo ranges of each satellite are obtained by multiplying speed of light by time the signal has taken from the satellite to the receiver. As there is accuracy error in the measured time, the term pseudo-range is used rather than range for such distance [17].

3.4 Operating Frequency

Fundamental frequency of 10.23 MHz is produced by automatic clock of GPS satellite. Two frequencies L1 (1.57542 GHz) and L2 (1.22760 GHz) are derived of the fundamental frequency which act as a carrier wave to transmit information by GPS satellite. [14]

3.5 Applications

3.5.1 Mining

GPS makes sure that the operator keeps the truck on a predetermined course. Any deviation from the center line due to blockage of site due to fog and dust warns the operator through an alarm system. This system can be installed in all mining machinery during foggy weather. In this system all the machinery report their position to the central control station as shown in Fig. 13, where the data are analyzed and vehicles can be warned if they are on collision course. It is very important system where light and heavy vehicle work side by side. The system can alert the operator when minimum distance among vehicles is not maintained. The system takes into account a driver's reaction time (18).

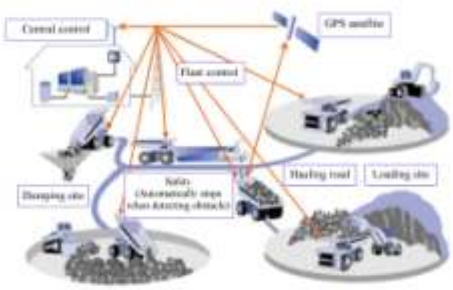

Fig. 13: Schematic diagram of GPS application in opencast mine [18]

3.5.2 Aviation

Aviation sector depends on GPS for navigation. Radar is currently being used in flights for the purpose of air traffic control. Automatic dependent surveillance-broadcast (ADS-B) system (Fig. 14) is used for air traffic control to take over from radar system. The system is comparatively more reliable due to greater accuracy and wider coverage area. ADS-B is like a large wireless network. The ground stations act as wireless access points and the aircraft as clients. Aircraft report their own position through the network and receive weather, traffic and other information from the ground network and other aircraft. ADS-B is significantly more accurate than surveillance radar because aircraft positions are updated once-per-second vs. between 4 and 12 seconds for radar [19].

GPS based navigation is used in USA by Medical pilots on pre-specified path. In coastline of Northern California, the Federal Aviation Administration has allowed Medical pilots to switch on GPS navigation system during dense fogs [20].

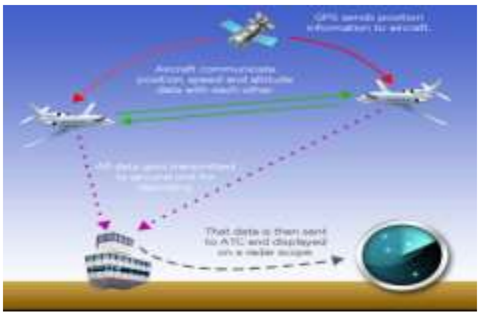

Fig.14: Schematic diagram of operating procedure of ADS-B system [21]

3.5.3 Railways

Winter season in India is harsh and foggy in nature. Indian Railways suffer maximum during winter season as trains are prone to delay and accident. Recently, North Western Railways of India employed GPS navigation to overcome these problems in railways. Signals on all railway stations on Jaipur–Rewari and Rewari–Bhatinda sections under North Western Railways have been equipped with GPS system. Train drivers would get all information about the signals, level crossing and stations in advance on a display of the anti-fog device. GPS devices provide accurate information about the location of the train and the track congestion. Fig. 15 illustrates the entire procedure of such a system [22].

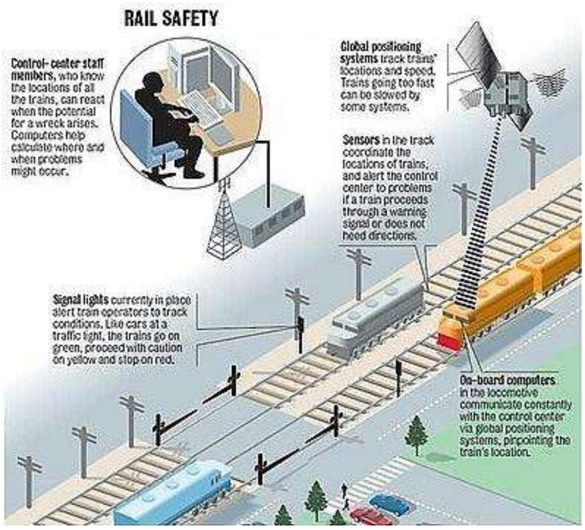

Fig. 15: Schematic diagram of GPS based navigation in Indian Railways [23]

3.5.4 Road Transport

GPS navigation system is used in public transport for navigation purposes. However, it cannot identify an obstacle in path of movement of vehicle under low visibility.

4. INFRARED THERMOGRAPHY

Infrared thermography is a technique which is non-contact in nature. The method uses an infrared energy to detect, display and record thermal patterns and temperature across the surface of an object. This equipment senses infrared radiation by converting it into temperature and displays image of temperature distribution as shown in Fig. 16.

Fig.16: View of same image by normal camera and thermal image camera [24]

4.1 Working Principle

Infrared radiation is emitted by all objects based on their temperatures, according to the black body radiation law (**25**).

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Thermography is used to see one's environment with or without visible illumination. Radiation emitted by an object increases with rise in temperature. Therefore, thermography allows one to see variations in temperature. A special camera can detect this radiation in a way similar to an ordinary camera does visible light. It works even in total darkness because ambient light level does significantly influence its operation. A thermal imaging camera is capable of processing algorithms to interpret those data and build an image as shown in Fig. 17 [26].

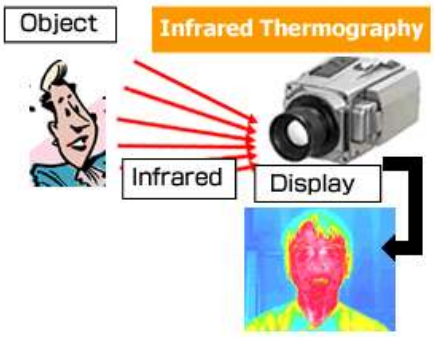

Fig. 17: Schematic diagram of operating process of infrared thermography [27]

4.2 Signal Routing

Image is formed by an optical system using infrared radiation. Subsequently, thermal detector converts infrared radiation into electrical signal which falls on them. Finally, conversion of electrical signal into an image is done by electronic processor which is exhibited in display unit. Range of infrared red thermography depends on sensitivity of sensors. Block diagram of signal routing is shown in Fig.18.

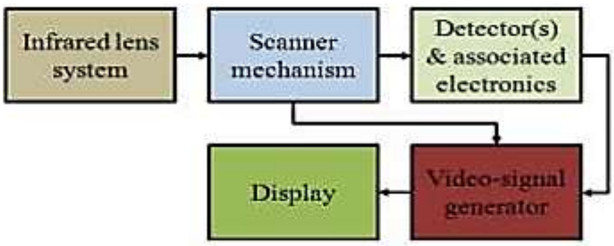

Fig. 18: Block diagram of signal routing in infrared camera [28]

4.3 Operating Frequency

Wavelength for IR thermography is given in Table 2 [28]. In thermo-grams, temperatures are displayed in a spectrum of colours.

Table 2: Wavelength of infrared light

Type of infrared light	Wavelengths
Near infrared	0.7–1.3 μm
Mid infrared	1.3–3 μm
Thermal infrared	3–30 μm

There are two wavebands of importance for thermal imaging cameras: 3.0–5 μm medium wavelength infrared (MWIR) and 8–12 μm long wavelength infrared (LWIR). They are part of thermal infrared light. The 5–8 μm frequency band is blocked by spectral absorption of the atmosphere by water vapor to such a tremendous extent that it is rarely used for imaging [29].

Thermal cameras are equipped with uncooled and cooled type of sensor. The uncooled sensor detects LWIR band between 7 and 14μm [29]. All the terrestrial targets emit most of their infrared in the same bandwidth. Cooled sensors are chilled to cryogenic temperature and are very sensitive to small change in temperature. They are designed to be used in MWIR and LWIR bands.

4.4 Applications

4.4.1 Mining

Thermal imaging cameras are being used to improve visibility in mines and avoid accidents causing loss of life and property. Thermal image technology provides additional visibility in blind spots of adverse environment conditions like dust and fog. Thermal cameras detect heat instead of light; hence the camera clearly detects machines, cables and other warm objects as shown in Fig. 19. Normally, a driver can see upto 20 m distance using vehicle's headlight in night, whereas a driver can see upto 500 m distance using thermal image camera [30]. Further, recording of thermal image for 72 h duration helps the engineers to investigate the cause of accident, if any. Also internet protocol (IP) enabled cameras are used for receiving live videos anywhere and anytime by using normal internet connections. These cameras not only improve visibility in mines but help to create a log of temperatures of nearby machines and cables in hazardous and explosives areas.

Fig. 19: Thermal image of dozer in a mine [31]

4.4.2 Aviation

Thermal imaging camera adds visibility to a pilot flying in darkness. It is useful in light fog, and windy and dusty conditions. It enhances pilot's capability to judge locations of terrain and flight from a long distance as shown in Fig. 20. These are used in unmanned aerial vehicle (UAV) for military and civilian purposes. UAV's flies at low altitudes and uses thermal imaging camera to fly even in darkness. The camera is IP enabled and it is down linked to a station on ground giving live picture. This can help in maintaining traffic on foggy days as well as at night.

Fig. 20: View of flight runway using visual image and Thermal camera Image [32]

4.4.3 Railways

Thermal imaging camera (Fig. 21) is one of the best devices to detect an obstacle on railway crossings. Using thermal sensors, the cameras can detect anything in a range of 100 m to 2 km in foggy and dusty condition . Currently this system is being usedby Israeli Railways [33]. The system has video analytics and IP enabled thermal camera having capability of sending live feed to control room operators. If a motor vehicle remains on the tracks for a predefined amount of time, the system alerts the control-room operator who can decide on how to respond with the situation.

Israel Railways has achieved a measurable reduction in train-motor vehicle crashes. They are now considering for other applications where thermal imaging may be used to increase passengers' security and safety [33].

Fig. 21: Thermal camera installed in Israeli Railways [33]

4.4.4 Road Transport

FLIR PathFindIR system installed in Portland, USA is a compact thermal imaging camera that significantly reduces the hazard of night time driving. Automotive night vision systems enable drivers to detect and monitor potential hazards on or near the road, allowing more time to react to any potential danger. PathFindIR thermal imager helps the user to recognize pedestrians, animals or other objects in total darkness, smoke, rain and snow as shown in Fig. 22. PathFindIR module can be integrated into vehicle for enhancing visibility in foggy weather .

Fig. 22: Thermal imaging camera in a car during night time [34]

5. OTHER TECHNOLOGIES FOR MINING APPLICATIONS

5.1 Bio Motion Clothes

Studies conducted by Wood et al. (2013)[26] have demonstrated that by incorporating retro reflective markers on clothes in a "bio motion" configuration the pedestrian visibility is improved for drivers at night, where the retro-reflective strips are illuminated by the beams of oncoming vehicles.

Capability of a driver to spot any pedestrian is increased two folds by use of bio motion sensor clothes. Visibility of a pedestrian is 69 m using only vest coat whereas it is 190 m using bio motion clothing as shown in Fig. 24 [35].

Fig. 23: Obstacle illumination in darkness using normal retro reflective waist (shown in left) and bio motion sensor (shown in right) [35]

5.2 Internet of Things

It is an emerging technology based on convergence of wireless technology, micro-electro-mechanical systems (MEMS) and Internet. Using Internet of Things (IoT) production of mines and safety of miners can be increased. This technology connects machines, fleets and people using radio frequency identification device (RFID) which allows data to be transferred over a network without human to human or human to computer connections. More than improving traceability and visibility of entire operation the IoT enables the computer to observe, identify and understand different aspects of mining operations without human intervention.

5.3 Robotics

Armed with radars and thermal camera a robot can do a variety of jobs in mining where working of humans are near impossible. Robotic devices powered by artificial intelligence can perform a range of tasks including drilling, blasting, loading, hauling, bolting mine roofs as well as ore sampling and rescuing trapped miners .

5.4 Proposed Technology

Ideally robots can be used for carrying out various mining activities. But this will create a wave of jobless workers. Best way to overcome this situation is to develop a helmet that is laced with radar and thermal sensors thereby allowing the miners to continue operation in low visibility. The helmet with the use of thermal camera and radar can see the terrain even low visibility. Army personnel across the world use camera with IP address on helmet and give live pictures in command center. Instead of using a normal camera, when thermal cameras with IP, radar and mobile or tablet are integrated with helmet using helmet mount the visibility can be improved drastically, which can help miners to continue production in foggy weather.

The helmet contains a phone with a heat sensor camera attached to it .Output of the camera is viewed on screen of the phone as shown in Fig. 24. The camera and phone is attached with the tripod on the helmet (Fig.25) and is placed in front of the eyes of the miner who is using the camera. The miner can switch on the camera in low visibility condition. The camera is IP enabled and live view can be seen from base station too. This setup helps to continue production in opencast mineduring foggy weather.

Fig. 24: Smart phone with heat sensor camera [36]

Fig.25: Helmet integrated with thermal camera [37]

Other way to continue production in opencast mine in foggy weather is use of GPS. The miner may be provided with a GPS device or a smart phone. All the machinery and miners fitted with GPS devices report their position to a command center. The command center in return relays any hazardous situation to the respective miner or operator.

Finally, a bird's eye view on an opencast mine helps for continuous monitoring of mining operations. A battery powered drone may be integrated with an IP enabled infrared camera for taking bird's eye view of an entire opencast mine. The miners, operators and equipment can be controlled with the help of a single drone or more than one drone depending upon area of an opencast mine. The infrared camera mounted on drone relays mining traffic images or videos to a control station of entire mine on real time basis during dark or foggy weather. In case of a hazardous situation in a specific area, the control station can react in time to avoid any damage by giving prior warnings. The drones can also help in rescue operations in mines in case of accidents as deployment of drones is not dependent on mine traffic. They can also be used to deliver first aid in case of minor injuries to operators or miners.

6. COMPARISON OF DIFFERENT TECHNOLOGIES

Each technology has its own advantages and limitations (Table 3). Depending upon the need and requirement, weather condition and terrain plays an important role in selecting the technology.

Table 3: Comparison of different technologies for operation in foggy weather

Technology	Radar	GPS	Thermal camera
Terrain	All terrain use.	Depends on positioning of satellite. Difficult to use under closed area.	All terrain use. Sensors range decreases around dusty area.
Range	Range is determined by run time of high wave frequency signal.	Range depends on positioning of satellite.	Range depends on sensitivity of thermal sensor.
Weather	All weather use,	GPS precision depends on weather condition.	Affected by fog phenomena.
Cost effective	Cost effective	Cost effective	Costly
Control	Self-controlled	Satellite controlled	Self-controlled
User Friendly	User friendly	User friendly	User friendly

6.1 Advantages

Radar is an all-weather technology. Independent of medium it travels in. It is flexible in nature and can be used in number of ways. It can be used in stationary and moving modes. It can detect a variety of target at a time. Less susceptible in weather compared to laser.

GPS is also an all-weather technology. It is comparatively cheaper than other navigation systems. The technology is regularly updated to include new terrains. Thus, it is very reliable.

Infrared thermography shows visual picture so that temperature of a large area can be compared. It can catch moving target in real time. It can be used to measure or observe in areas inaccessible or hazardous for other methods.

6.2 Limitations

Radar poses multiple tracking problems during a few occasions. If the target is closer to radar, the receiver gets saturated. If the radar is held in hand it can falsify reading. The interference caused by waves of same wavelengths but in different phase can constructively or destructively produces a resultant of zero.

Use of GPS depends on number of satellite connection available from that region. GPS signals are not always accurate due to obstacles presented to the signals such as hills, buildings, trees and sometimes by extreme atmospheric conditions such as geomagnetic storms.

The quality of camera used in infrared thermography depends on price of the camera. Accurate measurement depends upon emissivity of the surface and its reflective properties. Images can be difficult to interpret accurately for certain type objects, specifically objects with erratic temperatures and erratic background, although this problem is reduced in active thermal imaging [27].

7. CONCLUSIONS

In mining environment, fog and dust play major role in the outcome of production and safety of miners and operators. Improving visibility is of utmost importance. Each technology has its own advantages and drawbacks. Only integration of these technologies together can make working environment more productive and safer. Sensors that can detect both infrared waves and microwaves are already in use for detection of motion of an object. When the sensors are deployed with radars and thermal cameras, the problem of visibility for the operators and miners may be solved.The operator's safety can be increased by integrating all the above technologies together. The user can switch among the technologies as per the requirement of terrain and weather conditions.

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