Design and Evaluation of an Electronic Eye for Fire Detection in Human Space Capsule

Monish Moger B
Department of CSE and CORI
PES University
Bangalore, India
monish72003@gmail.com

Abhishek H
CORI
PES University
Bangalore, India
abhishekahippargi19@gmail.com

Pranav B
Department of ECE and CORI
PES University
Bangalore, India
pranavrbidare@pesu.pes.edu

Pubali Roy
Department of ECE and CORI
PES University
Bangalore, India
pubaliroy@pesu.pes.edu

Priya Bharadwaj
Department of ECE and CORI
PES University
Bangalore, India
priyabharadwaj@pesu.pes.edu

Akash Gupta
Human Space Flight Technology
Space Applications Centre, ISRO
Ahmedabad, India
guptaakash@sac.isro.gov.in

Payal Sharma
Human Space Flight Technology
Space Applications Centre, ISRO
Ahmedabad, India
payal@sac.isro.gov.in

Manikandan J
Department of ECE and CORI
PES University
Bangalore, India
manikandanj@pes.edu

2022 IEEE International Conference on Aerospace Electronics and Remote Sensing Technology (ICARES) | 978-1-6654-6191-7/22/$31.00 ©2022 IEEE | DOI: 10.1109/ICARES56907.2022.9993503

***Abstract* – Fire is often considered as a good friend, as it helps human in several ways, but the same is also considered as a dangerous foe, once it gets out of control. Fire can burn almost anything in no time and also depletes oxygen from the surrounding atmosphere, thus leading to casualties due to lack of oxygen, smoke and suffocation. Hence there is an urge to design early fire detection systems that can sense the initiation of fire and in turn activate the extinguishers to extinguish the fire, reducing the loss of property and life. In this paper an attempt is made to design and evaluate Electronic eye (E-Eye) for early fire detection in a human space capsule. Two variants of E-eye are proposed and their performances are compared. An attempt is also made to employ the concepts of machine learning using Generative Adversarial Network (GAN) models for fire detection. Maximum recognition accuracy of 100% with a prediction time of around 80ms was achieved using the proposed model. The proposed work is an outcome of a funded project from Indian Space Research Organization. The proposed prototypes can be easily employed in other places too such as houses, offices, storeroom, garage, etc.**

Keywords – Fire Detection, Electronic Eye, Embedded System Design, Human Space Capsule.

I. INTRODUCTION

Fire has benefitted humans in several ways like cooking, welding, space technology, aerospace program, construction and many more. Fire has also led to chaos and tragic accidents, when out of control, leading to loss of property and lives. This has motivated researchers to work in the area of automatic fire detection.

Human space capsule is often called as crewed spacecraft which accommodates astronauts to carry out studies and research of outer space. The space capsule has an ability to reenter the Earth's atmosphere without wings for the safe return of astronauts. Human space capsules consist of several electronic systems and cable harnesses. Though there is very poor chances of any spark or fire accident within the capsule, but there is a need to design an early fire detection system as a part of safety measures for the astronauts on-board. The early fire detection system should be capable of detecting and electric spark and fire, which would in turn raise an alarm for astronauts to take action. Alternatively the fire detection system output is connected to an extinguisher system that automatically extinguishes the spark or fire detected by spraying the appropriate extinguisher.

Human nose is capable of smelling a wider variety of gases/chemicals produced from pleasant items such as perfumes, flowers, dishes, etc. to unpleasant and pungent smell produced from rotten food, drainage, burning of rubber, plastics, etc. Animals like bear, shark, elephant, snake, dogs possess a stronger sense of smell. This has motivated researchers to mimic the characteristics of nose to design an Electronic Nose for the detection of fire. The limitation with Electronic nose is that the gases/chemicals to be sensed should come in contact with the sensor of the E-nose, and it depends on the direction of wind or airflow, thus increasing the response time of E-nose to fire detection. Also the drifts in sensitivity of sensors over a time, inability to provide absolute calibration, relatively short life of some sensors are additional limitations to E-nose.

Considering the limitations of E-nose, an attempt is made to design an Electronic Eye (E-eye) for early fire detection which can detect fire as well as the initial spark which leads to fire at a later stage in most of the cases. Based on the size of the human space capsule, more than one E-eye can be mounted at different places that are prone to initiate fire. The proposed work can be easily applied to other places like houses, offices, storerooms, garages, industries, motor rooms and many more for the early detection of fire.

II. LITERATURE SURVEY

A lot of research has been carried out in the area of early fire detection with the majority of papers focusing on forest

Funded by Indian Space Research Organization (ISRO), under Sponsored Research (RESPOND) program with project No. ISRO/RES/3/896/ 21-22 titled "Study, design and development of Electronic Nose for fire detection system".

fire and wild fire. An overview of early forest fire detection using optical remote sensing technology from airborne and space borne systems are reported in [1], using optical and infrared imaging sensors mounted on unmanned air vehicles for early wildfire and smoke detection is proposed in [2], using unmanned air vehicles and Long Range (LoRa) WAN sensor network for forest fire detection is proposed in [3], using a combination of thermal and visual cameras for forest fire detection is proposed in [4].

Design of a fire detection system within buildings by collecting and monitoring parameters like temperature humidity, smoke and occupancy is proposed in [5]. Design and development of fire smoke detectors in aircraft cargo compartments and containers is proposed in [6,7]. Design of an electronic nose with 32 sensors to monitor breathing air in a spacecraft, developed at Jet Propulsion Laboratory is reported in [8]. Performance evaluation of two smoke detectors for spacecraft on International Space Station was carried out and the results are reported in [9]. Design and development of a spacecraft fire detection system using PIC24HJ series microcontroller and LED based absorption spectroscopy sensor, slated for an upcoming sub-orbital flight test is proposed in [10]. Design of electronic nose to monitor the quality and quantity of volatile flammable liquids is proposed in [11]. Advancement of NASA's E-nose device to sniff COVID-19 from human breath is reported in [12]. Thermography of a C-type asteroid is performed using thermal infrared imager onboard Hayabusa2 spacecraft is reported in [13]. Thermogravimetric analysis for the identification of outgassed compounds on spacecraft, due to orbital thermal environment using infrared spectrometry and/or mass-spectrometry is proposed in [14]. A study on impact of internal heating of systems on the thermal signature of a spacecraft using thermal camera module and thermal modeling package simulation tools is reported in [15].

III. PROPOSED DESIGN FOR E-EYE

In this section, details about the prototypes of Electronic eye (E-eye) designed for early fire detection is reported. Two variants of E-eye are proposed here with the list and bill of materials used for these variants reported in Table I. Combination of different modules reported in Table I is also possible. Though Raspberry PI 4 module is a very powerful controller, but ESP32 module has a smaller form factor when compared with Raspberry PI module and hence a compact E-eye can be designed using ESP32. Alternatively Raspberry Pi Zero module having almost same form factor as ESP32 and costing around $10 can be used in the place of Raspberry PI 4 module. Two thermal cameras were explored for the proposed work and a comparison between their main features and specifications is given in Table II. It can be observed from Table II that Lepton thermal camera gives a better resolution for a scene with a 50°(Azimuth) × 60°(Elevation) field of view, whereas MLX90640 thermal camera has a wider field of view 110°(Azimuth) × 75°(Elevation), with relatively lower resolution. It is also observed that the power consumption of MLX90640 camera is around 2.5 times lesser than that for Lepton 2.5 camera and MLX90640 is around 3.5 times cheaper than Lepton camera. Based on the area under surveillance, expected field of view and resolution, one of these thermal cameras can be used.

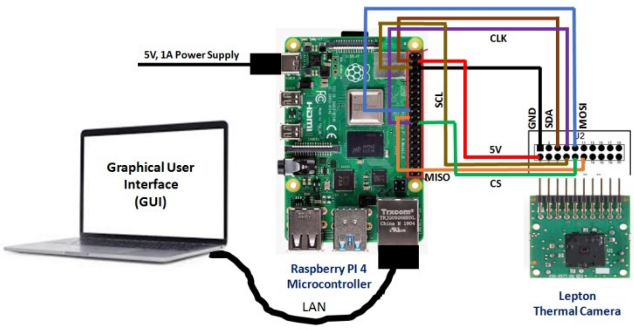
The connection diagram between a microcontroller and thermal camera for variant 1 and variant 2 is shown in Fig. 1(a) and 1(b) respectively. The Lepton camera in variant 1

TABLE I. COMPARISON BETWEEN PROPOSED VARIANTS OF E-EYE

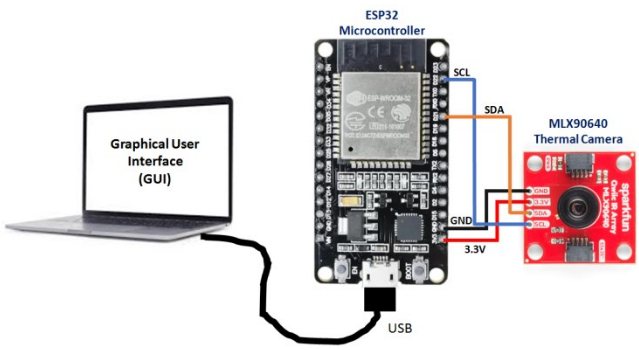
Sl. No.	Item Description	Variant 1	Variant 2
1.	ESP32 Module	-	$ 7.00
2.	Raspberry PI 4 Module	$ 35.00	-
3.	Lepton 2.5 Thermal Camera	$ 256.00	-
4.	MLX90640 Thermal Camera	-	$ 75.00
	Total	**$ 291.00**	**$ 82.00**

TABLE II. COMPARISON BETWEEN THERMAL CAMERA FOR E-EYE

Description	Thermal Camera	
	Lepton 2.5	**MLX90640**
Resolution in pixels	80(H) × 60(V)	32(H) × 24(V)
Field of View	50°(Az) × 60°(El)	110°(Az) × 75°(El)
Temperature Range	-10°C to 140°C	-40°C to 300°C
Interface	SPI and I2C	I2C
I2C Address	0x2A	0x33
Input Voltage	3V to 5.5V	3V to 3.6V
Power Consumption	160 mW	65mW
Price	$ 256.00	$ 75.00



(a) Variant 1



(b) Variant 2

Fig. 1. Connection diagram for proposed Electronic Eye.

uses Serial Peripheral Interface (SPI) to send its video stream and Inter-Integrated Circuit (I2C) communication as control interface. This is the reason for connecting both SPI and I2C interface with Raspberry PI in Fig.1(a). The images received by Raspberry PI 4 microcontroller board are transmitted to the Graphical User Interface (GUI) running on a laptop through Ethernet port connection. On the other hand, MLX90640 camera uses only I2C interface with ESP32 and the images received by ESP32 microcontroller board is transmitted to the GUI through serial port connection. After the performance evaluation of the proposed variants of E-eye, the laptop connection is removed and a buzzer is connected to one of the discrete output pins of the microcontroller board to raise an alarm for fire detection.

IV. Experimental Results

Details about all the experiments and assessments carried out using the electronic eye designed are reported in this section. Both the variants are connected to a laptop to assess the performance of Lepton 2.5 and MLX90640 thermal cameras. Snapshot of the test setup used for proposed work is given in Fig. 2. A graphical user interface (GUI) shown in Fig. 3 is designed using Python programming language to show the thermal image of a scene. The GUI designed has an option to set the threshold to distinguish between an image with fire and without fire (with background noise, if any). The GUI is also capable of displaying the thermal image along with the threshold set image to identify whether there is fire or not, as shown in Fig. 3. The normal output window displays the raw thermal image input, whereas the fire detector window displays the output based on the threshold set. In Fire Detector window, blue colored pixels represent no fire and red colored pixels denote the fire. The GUI can display the results from a single camera by pressing key ‘a’ to switch between the two cameras and can also display the results from both the thermal cameras on a single screen for comparing the outputs from both the thermal cameras for the same scene (A Candle was lit to compare the results), by pressing key ‘b’ as shown in Fig. 4. In order to record the screen displaying the performance evaluation and experimental results carried out, key ‘r’ shall be pressed. Keys ‘+’ and ‘−’ are used to increase/decrease the threshold value to set the best threshold that distinguishes fire from background noise. These features would help in studying the environment under test and to set an appropriate threshold.

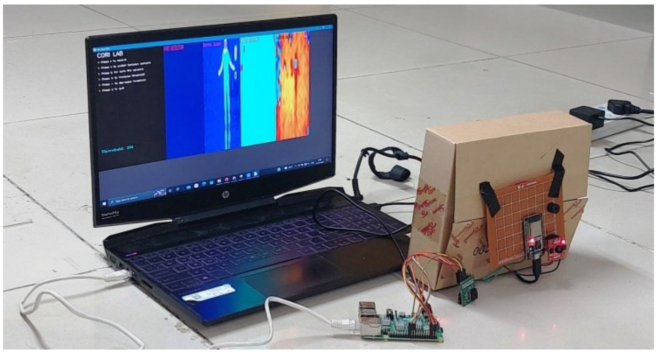


Fig. 2. Snapshot of the experiment setup for proposed Electronic Eye.

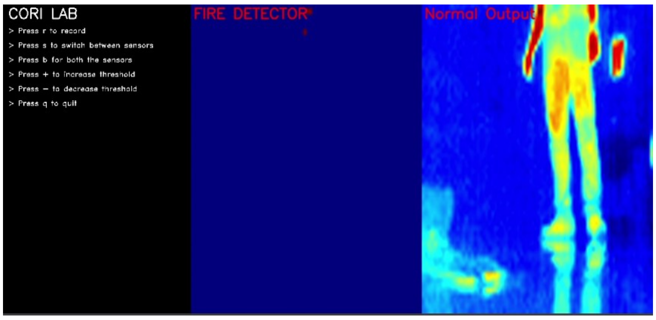
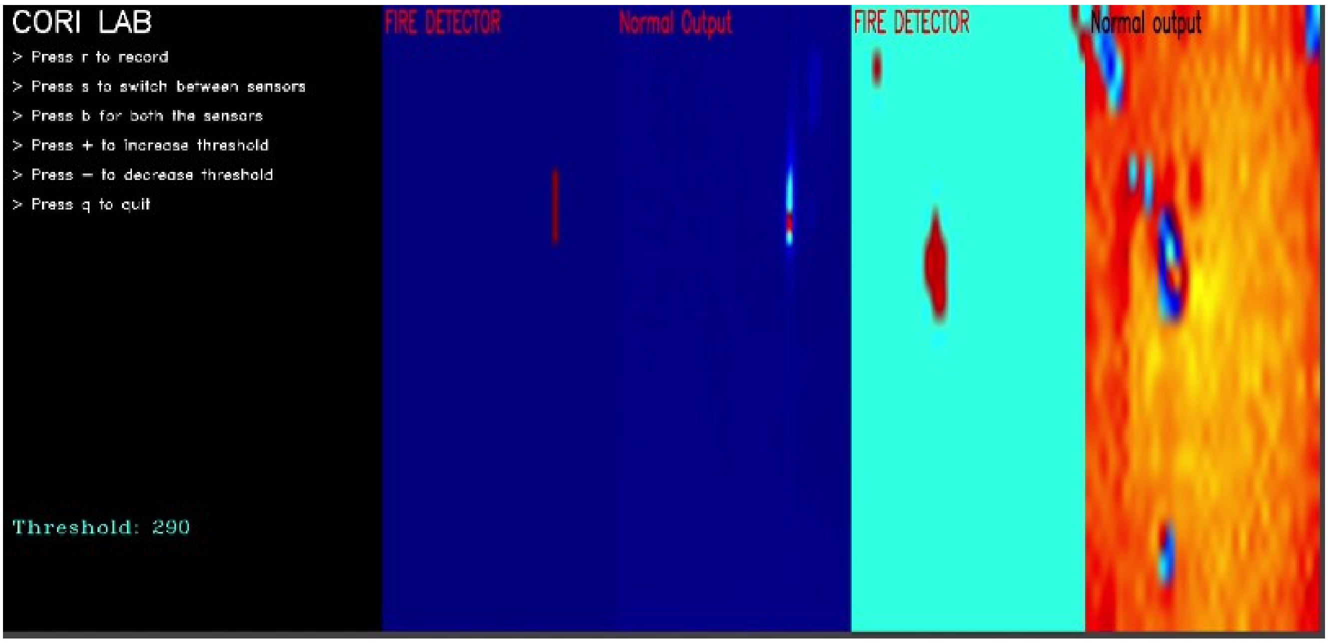


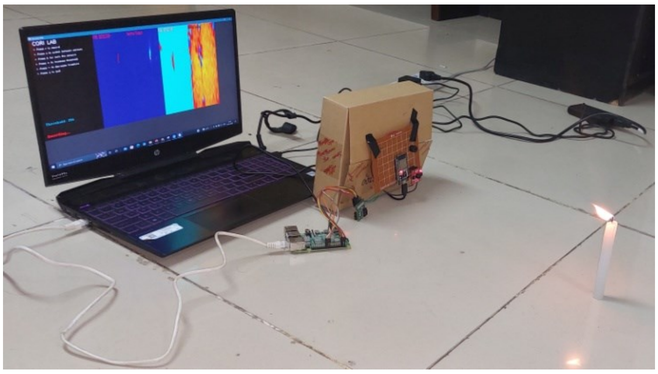
Fig. 3. Graphical User Interface designed for proposed Electronic Eye.



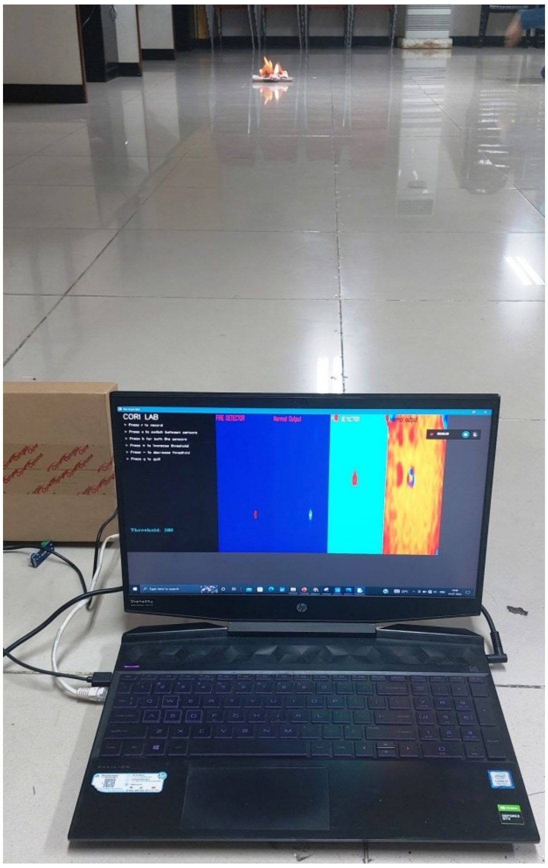
Lepton 2.5 Camera MLX90640 Camera

Fig. 4. GUI displaying output from both thermal cameras for a Candle lit test case.

Experiments were carried out to compare, assess and find the maximum range of fire detection using the proposed variants of E-eye. A candle was lit as shown in Fig. 5 (a) and the candle was moved backwards to measure the range of fire detection. During the experimentation, it was observed that only one pixel was red colored in fire detector window, when the candle was moved to 1m from the thermal cameras. Beyond 1m, the candle flame wasn't detected by both the thermal cameras. An attempt was made to increase the size of flame by burning paper as shown in Fig. 5(b). During this experimentation, it was observed that the fire was detected upto a maximum range of 10m, with only one pixel being red colored at 10m. These experiments confirmed that both the thermal cameras are capable of detecting fire at a distance of 10m and beyond based on the flame height. With most of the human space capsules being 10-12m long, the proposed electronic eye should be able to detect the fire within the human space capsule. For better results, two electronic eyes can be used at two sides for early fire detection, i.e., when the flame height is small.



(a) Using candle flame.



(b) Using burning paper having a larger flame size.

Fig. 5. Experimental results of proposed E-eye for fire detection

Sometimes fire is caused due to a high concentration of sparks possessing high energy imparted onto dry combustible material. In order to assess the performance of the proposed variants of E-eye to spark detection, a spark generation setup is established using the circuit from a mosquito bat and powered using DC power supply as shown in Fig. 6. Experiments similar to fire detection were carried out for spark too using the same GUI and the results are reported in Fig. 7. It can be observed from Fig. 7 that both Lepton2.5 and MLX90640 thermal cameras detected the spark. It was also observed during the experimentation that spark could be detected only up to a maximum distance of 30cms from the thermal camera on providing 5V as input to the circuit. This experimentation confirmed that the proposed E-eye can be mounted near the places prone to spark for spark detection before it leads to fire.

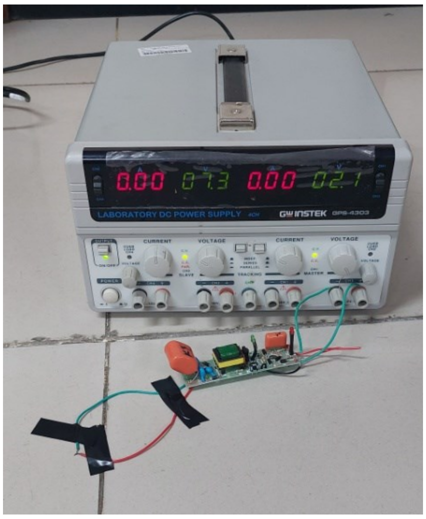
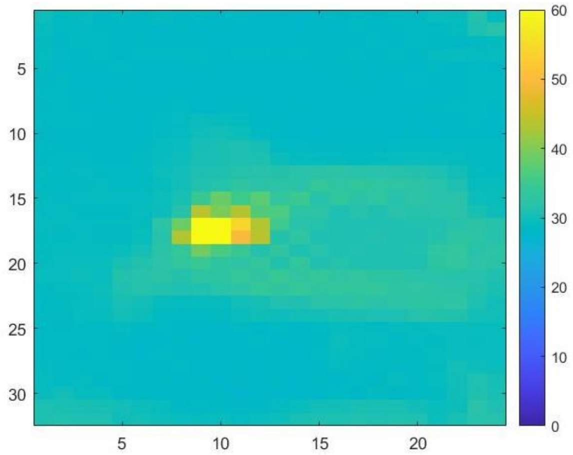


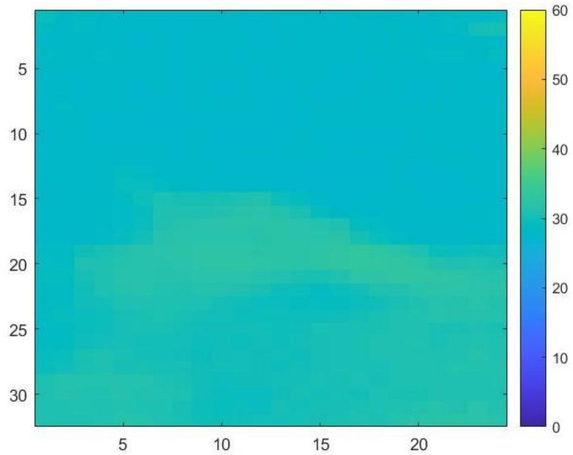
Fig. 6. Snapshot of experimental setup for spark generation

Fig. 7. Experimental results of proposed E-eye for spark detection

An attempt is also made to employ machine learning for the proposed E-eye. The thermal images obtained from thermal camera using the electronic eye designed are used to model a machine learning based fire detection system. Around 600 thermal images are collected from each variant with 300 images having fire and 300 images without fire. Sample thermal images used for the model with and without fire are given in Fig. 8 for MLX90640 thermal camera. It was observed during data collection that the thermal image from MLX90640 camera displays the temperature at a particular pixel using a thermal map as shown in Fig. 8 and is not a RGB image. Sample thermal images used for the model with and without fire are given in Fig. 9 for Lepton

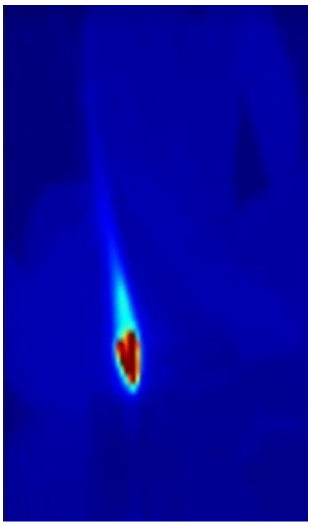


(a) With Fire

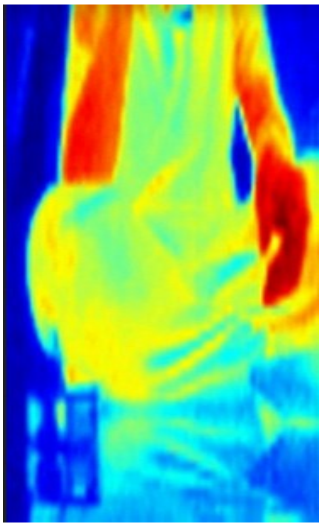


(b) Without Fire

Fig. 8. MLX90640:Sample images from E-eye for machine learning model.



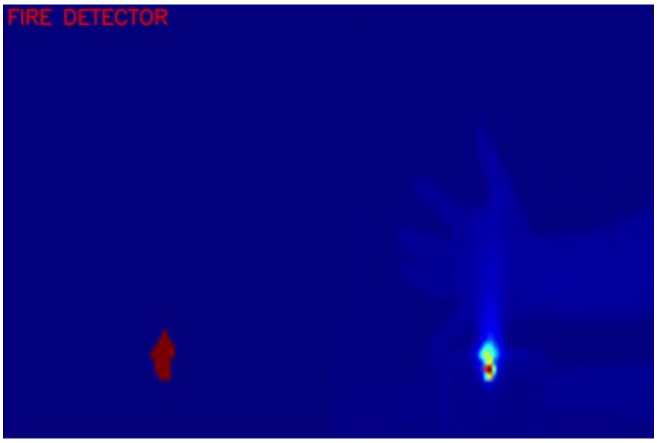
(a) With Fire



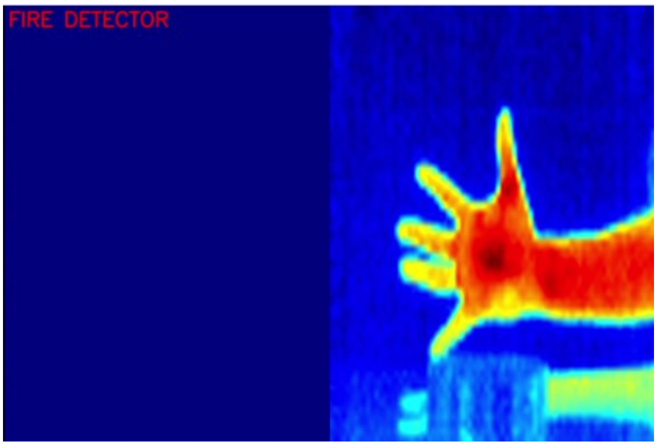
(b) Without Fire

Fig. 9. Lepton : Sample images from E-eye for machine learning model.

thermal camera. It was observed during data collection that the thermal image from Lepton camera maps the pixel with highest temperature in the entire scene to red color and pixel with least temperature to blue color and it is a RGB image. This is well illustrated in Fig. 10, wherein it can be observed that when a candle is lit, the hand is in blue color and when the candle light is turned off, the hand is in red color, as it has the maximum temperature at that instance in the scene under observation. This shows the dynamical mapping of thermal image based on the environment under observation. It can also be observed from Fig. 10(a) and 10(b) that the fire detector window detected only the fire and not the hand, even though the temperature of hand was red colored without fire.



(a) With Fire



(b) Without Fire

Fig. 10. Dynamic thermal mapping of Lepton camera.

The proposed machine learning based fire detection model uses Semi-supervised Generative Adversarial Networks (GAN). The block diagram for GAN architecture used in proposed work is shown in Fig. 11. GAN architecture consists of two modules: Generator and Discriminator. Generator generates fake images using random inputs and Discriminator is used to discriminate between real and fake images. In addition to discriminating between real and fake images, the discriminator also extracts features from the images and gets trained on class labels. Thus the GAN model is used as a two class classifier here to distinguish between the class labels: fire and no-fire. The input image is first resized into 28×28 pixels and fed to the discriminator. The generator model generates fake images of size 28×28 from random noise inputs, with the fake images being similar to the real images used for training and thus generating additional samples for training the entire GAN model. Once the training is complete, test images are fed to feature extraction part of discriminator network, followed by multi-class classifier discriminator to predict the class label for the test input. The proposed GAN based classification model for fire detection is designed and evaluated using the Python scripts and resources available in [16].

Details about the performance of GAN model for fire detection is reported in Fig. 12 for different epochs on using 12 samples for training, 200 samples for validation and 200 samples for testing. It can be observed from Fig. 12(a) and 12(b) that the proposed GAN model yielded a maximum accuracy of 100% on using just 12 training samples for both MLX90640 and Lepton images. This is because of the ability of the generator to generate fake samples for training the model, which are almost same as real images, thus increasing the number of samples for training internally. Similar results were obtained for experiments carried out by increasing the number of training samples to 200, with 200 samples each for validation and testing.

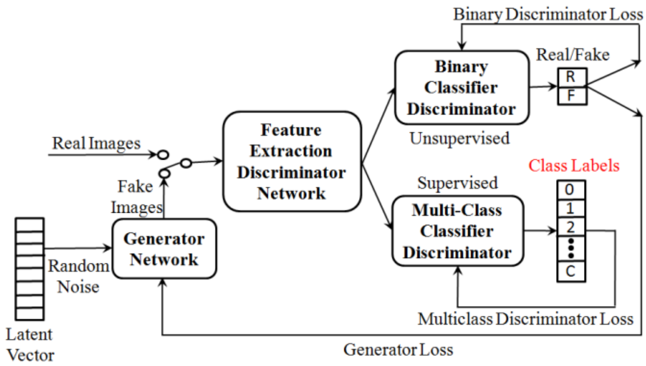
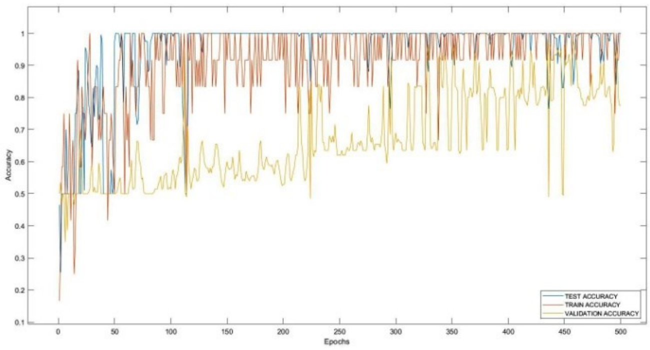
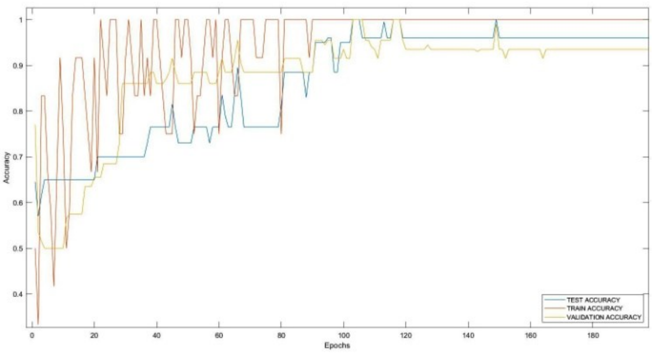


Fig. 11. Architecture of Semi Supervised GAN used in proposed work.



(a) MLX images



(b) Lepton images

Fig. 12. Epochs vs. Recognition Accuracy for the GAN model used.

Details about the training time for the GAN model and time required to predict fire/no-fire from an input image is reported in Table III. It can be observed from Table III that the training time and testing time for both MLX and Lepton image inputs are almost same, as both the input images are resized to 28×28 before training and testing. As expected, the training time increased for an increase in the number of training samples or epochs, but the prediction time is 76.2ms for Lepton and 82.2ms for MLX and almost same for all the GAN models used for proposed fire detection with models having different number of epochs and training samples.

TABLE III. COMPUTATION TIME FOR GAN BASED FIRE DETECTION

Description	#Samples	#Epochs	MLX	Lepton
Training Time	12	200	15.96s	15.70s
Training Time	12	500	38.22s	38.26s
Training Time	200	200	24.29s	24.35s
Training Time	200	500	61.75s	58.18s
Prediction Time	1	-	82.2ms	76.2ms

V. CONCLUSION

In this paper, design and evaluation of early fire detection systems, also referred to as Electronic Eye, capable of detecting initial electric spark and fire using two variants for human space capsules is proposed. Based on the experiments and evaluations carried out, it is observed that even though the resolution of Lepton camera is higher than that of MLX90640 thermal camera, but the later has a wider field of view over the former, with MLX90640 covering an additional 60°Azimuth and 15°Elevation over Lepton camera. Also MLX90640 is nearly three times cheaper over Lepton camera and has a wider range of temperature measurement. Based on the area under surveillance, expected field of view and resolution, one of these thermal cameras can be used. Though there are traces of noise in both, but both the variants are capable of detecting electric spark and fire. The experiments were carried out for a maximum range of 10m, as most of the human space capsules are 10-12m long. With machine learning being employed almost everywhere; an attempt is also made in this paper to evaluate the performance of the proposed fire detection model using Generative Adversarial Networks (GAN). Images from these two variants are fed to GAN model for the detection of fire. It is observed that both the variants yielded a maximum recognition accuracy of 100% with a prediction time closer to 80ms. The longer lifetime of electronic eye over electronic nose is considered as the major advantage of proposed work and also the proposed prototypes can detect fire at a distance of 10m, well before the gases can reach any E-nose at a distance of 10m. The proposed E-eye can also be easily employed for various other applications to safeguard human lives. The future scope of this work includes integration of proposed E-eye with E-nose for smoke detection to get the best of both worlds in early fire detection.

ACKNOWLEDGEMENT

The authors would like to thank the RESPOND team of ISRO, Dr. Abha Chhabra, Dr. Parul Patel, Mrs. Ankita Patel from SAC-ISRO, and Dr. MA Paul from ISRO HQ.

REFERENCES

[1] Panagiotis et al., "A review on early forest fire detection systems using optical remote sensing," *Sensors*, Vol. 20, No. 6442, pp. 1-26, Nov 2020.

[2] X Yang, L Tang, H Wang and X He, "Early Detection of Forest Fire Based on Unmaned Aerial Vehicle Platform," *Int. Conf. on Signal, Information and Data Processing*, 11-13 December 2019, Chongqing, China, pp. 1-4.

[3] G Hristov, J Raychev, D Kinaneva and P Zahariev, "Emerging Methods for Early Detection of Forest Fires Using Unmanned Aerial Vehicles and Lorawan Sensor Networks," *EAEEIE Ann. Conf.*, 26-28 September 2018, Hafnarfjordur, Iceland, pp. 1-9.

[4] M Sadi, Y Zhang, W Xie and A Hossain, "Forest Fire Detection and Localization Using Thermal and Visual Cameras," *Int. Conf. on Unmanned Aircraft Systems*, 15-18 June 2021, Athens, Greece, pp. 744-749.

[5] SK Mekni, "Design and implementation of a Smart fire detection and monitoring system based on IoT," *Int. Conf. on Applied Automation and Industrial Diagnostics*, 29-31 March 2022, Hail, Saudi Arabia, pp.1-5.

[6] R Zheng, S Lu, Z Shi, C Li, H Jia and S Wang, "Research on the aerosol identification method for the fire smoke detection in aircraft cargo compartment," *Fire Safety Journal*, Vol. 130, June 2022,

[7] Q Zhang, Y Wang, C Soutis and M Gresil, "Development of a fire detection and suppression system for a smart air cargo container," *The Aeronautical Journal*, Vol. 125, Issue 1283, pp. 205-222, January 2021.

[8] M Ryan *et al*., "The JPL electronic nose: Monitoring air in the U.S. Lab on the International Space Station," *IEEE Int. Conf. SENSORS,* 1-4 Nov 2010, Waikoloa, USA, pp. 1242-1247.

[9] M Meyer *et al.*, "Evaluation of Spacecraft Smoke Detector Performance in the Low-Gravity Environment," *Fire Safety Journal*, Vol. 98, Issue 5, pp.74-81, June 2018.

[10] C Kincaid, "Embedded systems development for spacecraft fire detection MIR optical sensor," Proc. SPIE 12107, Infrared Technology and Applications XLVIII, 121071E, May 2022.

[11] Z Wu, H Wang, X Wang, H Zheng, Z Chen, C Meng, "Development of Electronic Nose for Qualitative and Quantitative Monitoring of Volatile Flammable Liquids," *Sensors (Basel)*. Vol. 20, Issue 1817, March 2020, pp. 1-12.

[12] Frank Tavares, "NASA's E-Nose device advanced to Sniff COVID-19 from Human breath," *NASA Ames* , Apr 2021.

[13] Arai *et al.,* "Thermal Imaging Performance of TIR Onboard the Hayabusa2 Spacecraft," *Space Sci Rev*, Vol. 208, Issue 1-4, pp.239–254, July 2017.

[14] Zilong Jiao et al., "Outgassing environment of Spacecraft: An Overview," IOP Conf. Series : Materials Science and Engg., Vol. 611, pp. 1-8, July 2019.

[15] Carnahan S, Hanspeter S and Benjamin L, "Impact of Internal Heating on Spacecraft Thermal Signature." *AAS Spaceflight Mechanics Meeting,* 13-17 January 2019, Kaanapali, Maui, HI, pp.1-14.

[16] Sreenivas B, "Semi-supervised GAN", https://github.com/bnsreenu/python_for_microscopists/tree/master/259_semi_supervised_GAN, March 2022.