Mobile Head Detection with Thermal Imaging for Skin Temperature Analysis

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Abstract

This work investigates if a neural network small enough to run from a low-grade smartphone could be trained on low-resolution (120x160) infrared images to detect human heads for mobile skin temperature analysis. Several object detection models were trained to detect people from FLIR's ADAS dataset and EfficientDet D0 512x512 was determined to be the most accurate with 0.325 normalized total loss. A new dataset of 120x160 resolution infrared images was collected and used to retrain the model to exclusively detect heads. The final model achieved an Average Precision of 95.6% with IoU 0.5, and an Average Recall of 76.1% with a maximum threshold of 100 head detections. The model is currently deployed on the Covid ID Android application, where the localized head regions are passed to a module that performs skin temperature analysis.

Background

Fig 1: Guide IR236 Fever Warning System, on sale for 12,000 USD (AVE Business, 2020)

- Following the outbreak of SARS in 2003, researchers tried to leverage thermal imaging for fever detection. However, their technologies were often limited by:
  - High materials costs (sensors, computer, monitor)
  - Relying on strictly controlled environments (Chan et al., 2006)
- In response to COVID-19, new systems are being developed to perform infrared fever analysis (see Fig 1), but their prices still often range between $5,000-$30,000 (Bogaisky, 2020).
- As such, these systems are mostly marketed to governments, schools, and airports, and are not very accessible to the public.

Fig 2: A FLIR One Pro Camera, on sale for 300 USD (FLIR Systems, 2020)

Introduction

- In the United States, there have been over 7,000,000 cases of COVID-19 as well as over 200,000 COVID-19 related deaths as of September 30th, 2020 (European Centre for Disease Prevention and Control, 2020; National Center for Health Statistics, 2020).
- Fever is one of the most prevalent symptoms to manifest in patients infected with COVID-19 (Centers for Disease Control and Prevention, 2020).
- Heat signatures can be translated to images via thermal imaging in the Infrared spectrum
- Thus, if one could leverage thermal imaging to know if an individual near them had an elevated temperature, they might decide to avoid that person. This type of decision-making based on environmental information is known as Situation Awareness.

Hypothesis

- Utilizing modern machine learning libraries and a low-cost, commercial-grade, infrared camera, develop a system to perform live head localization and temperature analysis for fever detection.
- The Infrared Fever Indication System (IRFIS), deployed on the Covid ID Android mobile platform, could bring this technology to a global userbase.
- IRFIS could then help users increase their Situation Awareness (Fig 3)

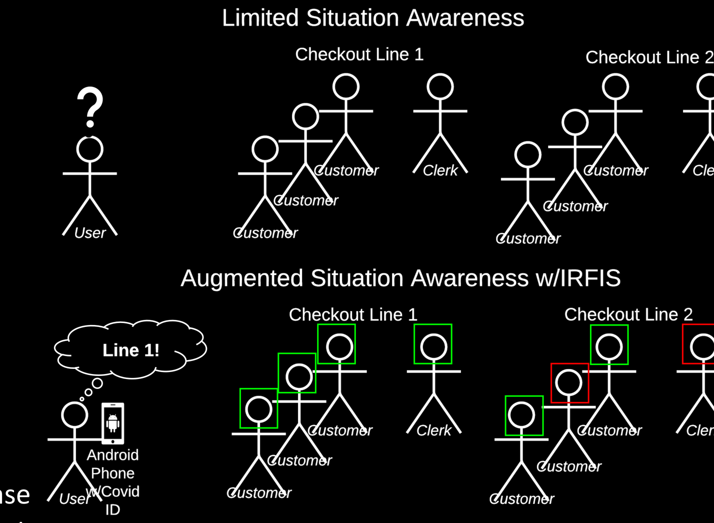


Fig 3: IRFIS example use case in store checkout

Materials and Methods

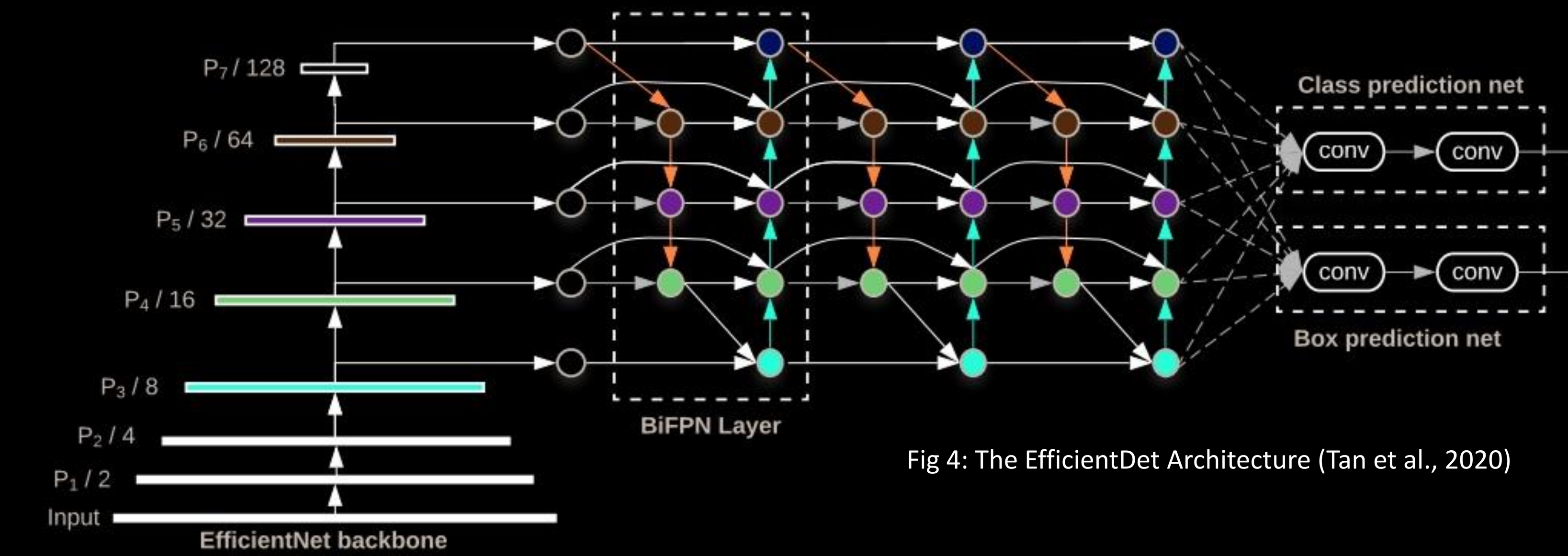
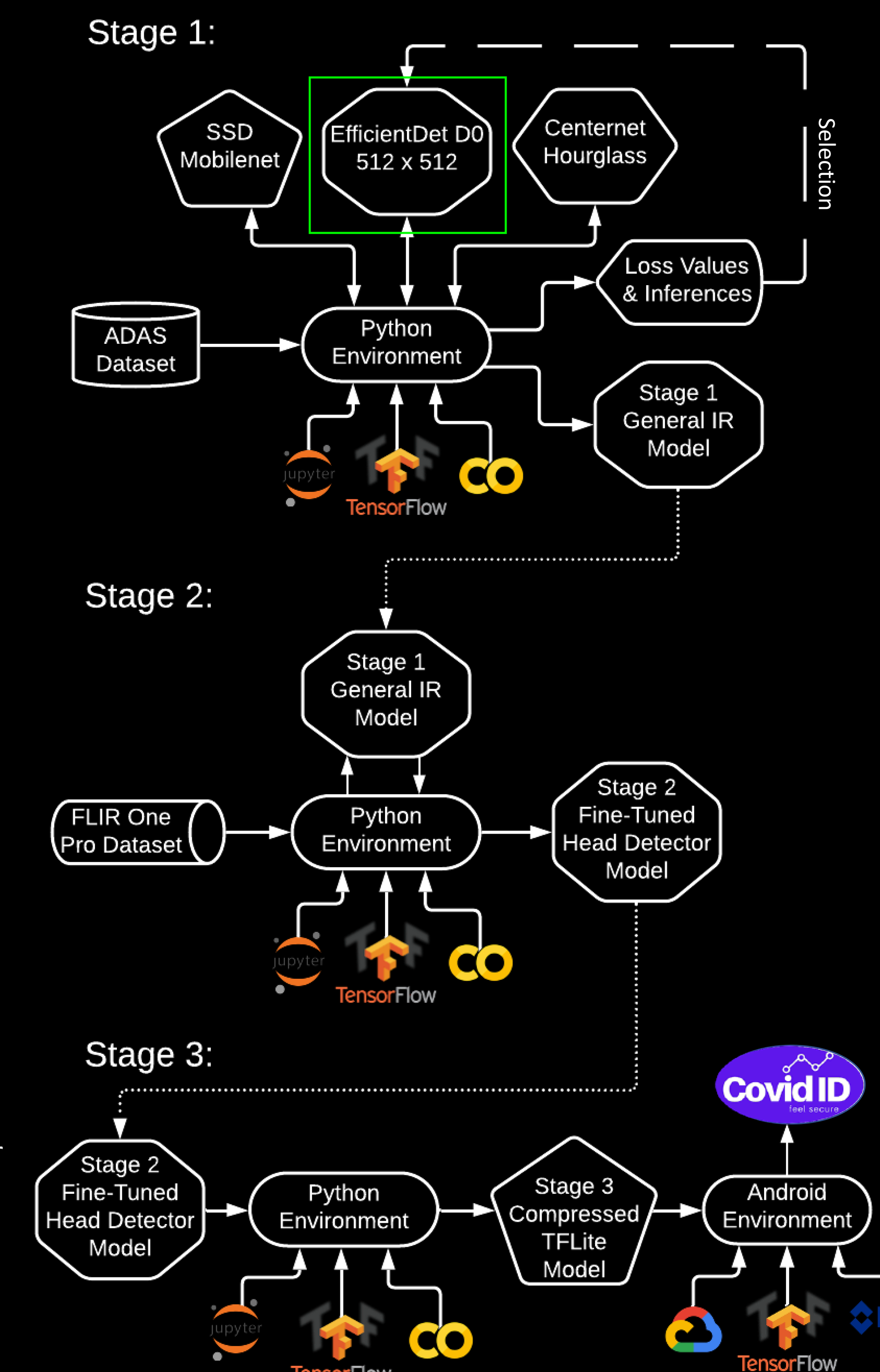


Fig 4: The EfficientDet Architecture (Tan et al., 2020)

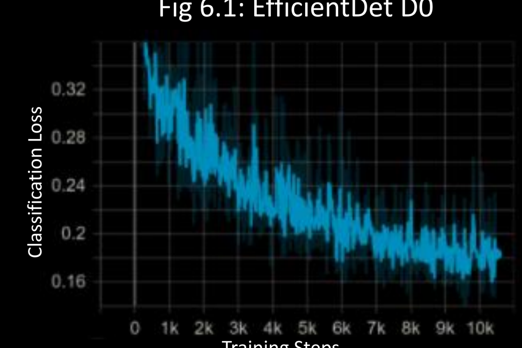
Fig 5: Systems Diagram for Stages 1-3 of IRFIS Development



- Stage 1 (Completed):
  - From the TF2 Object Detection Model Zoo, select candidate models to retrain for infrared object detection
  - Evaluate chosen models using FLIR's ADAS infrared image dataset for acceptable loss convergence
  - Select model with lowest loss value after retraining: EfficientDet D0 512x512 (Fig 4)
- Stage 2 (Completed):
  - Acquire new dataset w/FLIR One Pro infrared cameras (Fig 2)
  - Retrain Stage 1 model on this new dataset to detect heads
  - Evaluate model and determine that it is ready for deployment
- Stage 3 (Completed):
  - Compress model by converting to mobile-ready tflite format
  - Integrate model into Covid ID Android application
- Stage 4 (Prototype Complete)
  - Use FLIR Mobile SDK to extract live temperature data from images to perform temperature analysis
  - Display live temperature analysis results to the user

Selecting a Model: Stage 1 Results

Fig 6.1: EfficientDet D0



- Several small models were trained on IR datasets with COCO classes and loss values were compared (see Fig 6.1-6.5)
  - Low Loss → High Accuracy
- After evaluating several models, EfficientDet D0 (Fig 6.1, 6.2) was chosen for Stage 2 retraining based on:
  - lowest converging loss values
  - most stable convergence
  - model allowed for high batch size
  - inferences yielded best results (Fig 9.1)

Fig 6.4: SSD Mobilenet

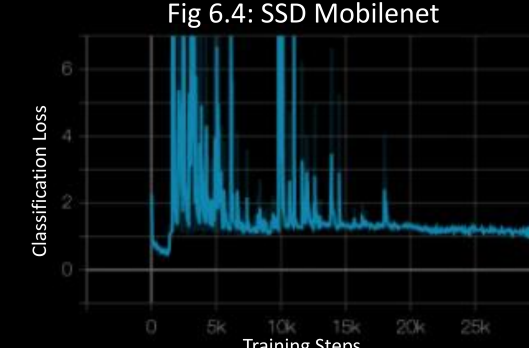


Fig 6.2: EfficientDet D0

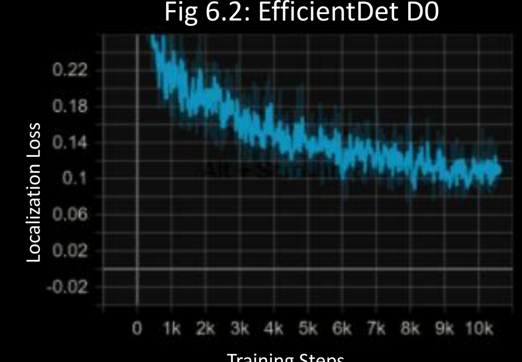


Fig 6.3: Centernet Hourglass

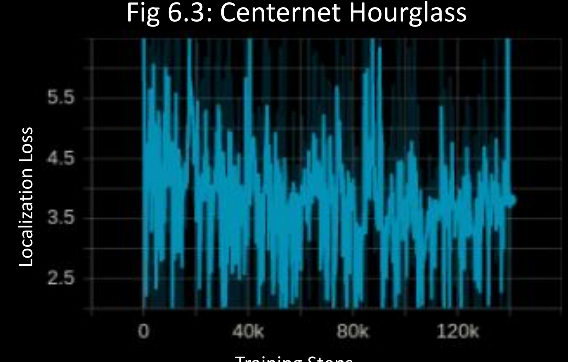
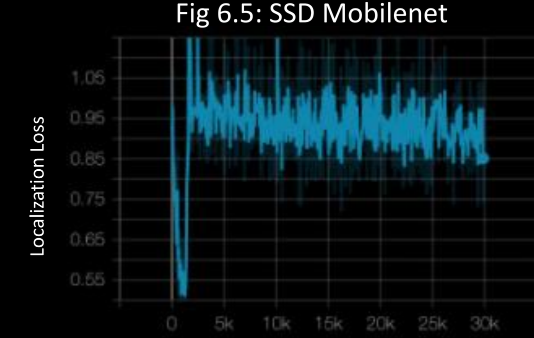


Fig 6.5: SSD Mobilenet



Fine-Tuning the Model: Stage 2 Results

- While retraining for head detection, the model total loss values converged to 0.05 total loss
- Superior Classification & Localization Loss
  - classification loss: the rate at which the detector failed to classify or incorrectly classified heads (Fig 7.1)
  - localization loss: how precisely the detector was able to draw bounding boxes around detected heads (Fig 7.2)

Fig 7.1: Classification Loss

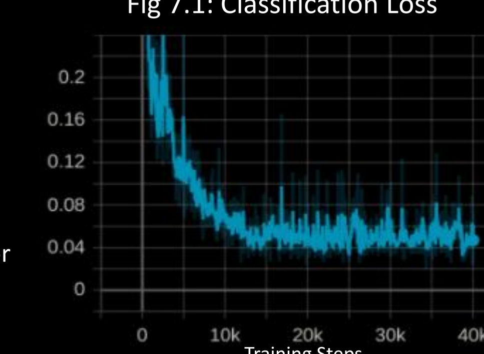


Fig 7.2: Localization Loss

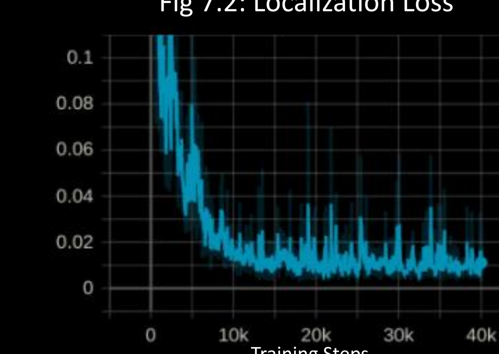


Fig 8.1: Average Precision & Recall by Detection Size

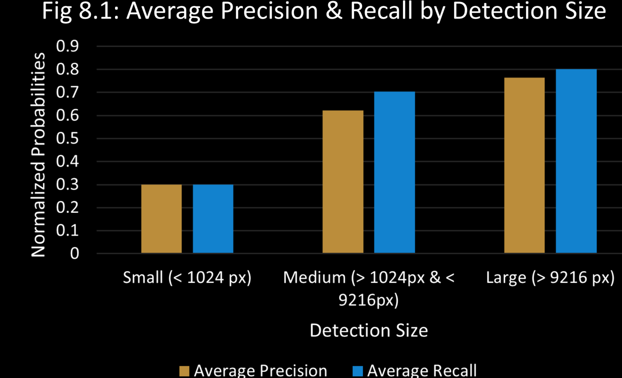
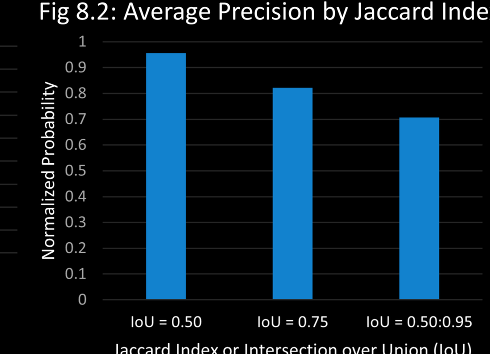


Fig 8.2: Average Precision by Jaccard Index



Trained model evaluated using two metrics:

- Average Precision (AP)
- Average Recall (AR)

- Precision and accuracy increase with head size, with an AP of 0.765 and AR of 0.802 for heads in the foreground (Fig 8.1)
- The detector achieved an AP of 0.956 with an IoU threshold of 0.50 (Fig 8.2)
- AP is high compared to AP of 0.522 achieved by Google's EfficientDet D0 general object detecting model when evaluated with same IoU (Tan et al., 2020).

Visualizing Results

Fig 9.1: Stage 1 Model

Fig 9.2: Stage 2 Model

- Figures 9.1-9.2 show some example inferences from the Stage 1 and Stage 2 Model respectively
- Figures 9.3-9.5 below show the mobile head detector correctly identifying a head with 100% certainty in three different instances and performing live temperature analysis

Fig 9.3: Frontal, Stage 4

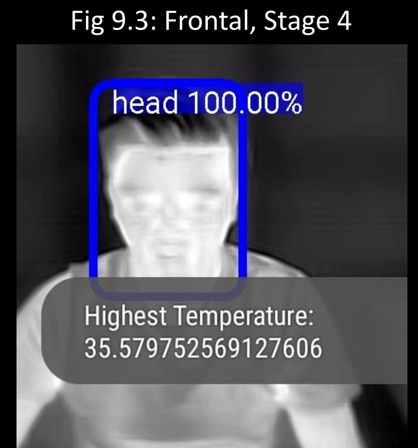
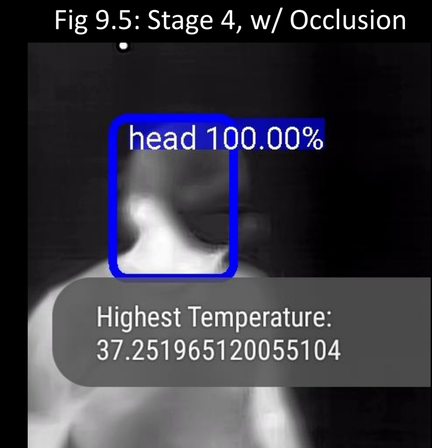


Fig 9.4: Profile, Stage 4

Fig 9.5: Stage 4, w/ Occlusion



Conclusion

- The Infrared Fever Indication System (IRFIS) presents a new tool for smartphone users to increase their Situational Awareness with respect to COVID-19
- The development of IRFIS' head detector was successful, achieving an AP of 95.6%, a surprising result given the low-cost, low-resolution infrared cameras used. The system operates well even with high occlusion (Fig 9.5)
- Our model has since been deployed on the Covid ID Android application (Fig 10)

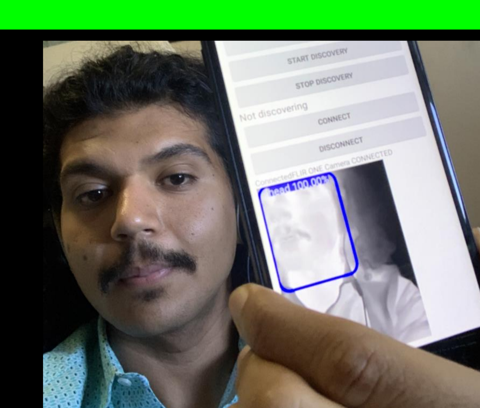


Fig 10: Stage 3 Result - IRFIS' head detector model deployed in the Covid ID Android application

- With the head detector model fully trained, compressed, and integrated into the Android application, we have developed a prototype system to analyze the infrared thermal data for robust temperature analysis and are displaying the results to the user
- IRFIS currently extracts the highest temperature located within the localized head regions, but we are also considering more complex methods for analyzing skin temperature. The system also serves as a proof-of-concept for the development of future low-cost mobile systems that could leverage machine learning based object detection in the Infrared spectrum for a variety of applications and bring this technology to a significantly wider userbase (Gallegos, 2020).

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