A Method to Track Informal E-Waste Burning: A Case Study in the West Bank

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This report represents work of one or more WPI undergraduate students submitted to the faculty as evidence of a degree requirement. WPI routinely publishes these reports on its web site without editorial or peer review.

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Abstract

Many informal e-waste processing hubs exist across the globe; these hubs represent an unregulated e-waste burning economy. This unregulated burning pose significant environmental and health issues. Efforts to address the burning of e-waste are threatened by the lack of information on frequency and location of burn sites. In the West Line Villages, these burn sites change frequently, making them hard to track. The present study proposes a streamlined reporting system for citizens to report burn events coupled with a method to automate burn detection through video recording as well as to record and track burns over time, while utilizing open source smoke detection software.

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Authorship

Jackson Baker, Amber Beliveau, Maxwell Lepage, Timothy Kendall and Erin Thibeault all contributed to the research and writing of this report. The following describes how the report was written for this project.

Jackson contributed to writing parts of the introduction and the methodology section pertaining to the streamlined burn reporting system. Mr. Baker also was responsible for the data collection, visualization, and creation of the burn reporting website.

Amber was responsible for the authorship of the abstract. Ms. Beliveau also authored parts of the introduction pertaining to health and environmental effects, and the methods and results pertaining to the time lapse footage.

Maxwell authored parts of the introduction, methodology, and results chapter, especially those parts pertaining to image processing and global e-waste trends. Mr. LePage also worked with Ms. Thibeault to develop a conceptual image processing pipeline. From this conceptual pipeline, Mr. LePage wrote a python script to detect smoke in images.

Timothy authored parts of the introduction and discussion and helped to transition the writing towards that of a journal article. Mr. Kendall researched citizen science elements and connected the research to the global e-waste context.

Erin was responsible for writing the initial draft of the methodology chapter and contributed to the conclusion and results sections of the report. Ms. Thibeault contributed to the initial research and prototype of the image processing software.

In addition to writing individual sections of this report, Jackson Baker, Amber Beliveau, Maxell Lepage, Timothy Kendall and Erin Thibeault all edited the paper for grammar, content, and flow as a group.

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Introduction

The term “electronic waste” or “e-waste” encompasses any electronic devices that have reached the end of their usable life and have been discarded (Widmer, 2005). The accumulation of e-waste is a growing problem, as more cell phones, cables, computers, and other electronics are produced and disposed of. E-waste is referred to as “the world’s fastest growing single waste stream”, noting increasing trends of e-waste generation that are predicted to continue increasing in the upcoming decades (Shittu et al., 2021). Although there are formal recycling industries in some countries to dispose of this waste (Terazono et al., 2006), a large amount of e-waste ends up being processed by informal sectors in specific and highly localized regions of developing countries. This waste tends to consist of foreign imports, however, the developing countries that process the most e-waste are also home to the fastest growing electronics markets; as such, these informal hubs also process a non-negligible amount of domestic e-waste [Iqbal et al., 2015; Sajid et al., 2019; Widmer et al., 2005]. There, it becomes a vital source of income. Some electronic equipment is in good enough condition to be refurbished and resold, and the remainder of the waste is dismantled to extract the valuable raw materials. Dismantling can be done through a variety of means, but one of the most common and easily implemented methods is open burning, where plastic components are burned away in order to collect the metal within. [Widmer et al., 2005; Gangwar et al., 2019].

E-waste burning produces thick black smoke that contains a multitude of harmful airborne pollutants including fine particulate matter, heavy metals, and volatile organic compounds (Robinson, 2009). Some of the health conditions that have been associated with this pollution are as follows: lung damage, weakened immune system (Davis & Masten, 2020), miscarriage, infertility in both men and women (Plum et al., 2010), and gastrointestinal issues (Gaetke & Chow, 2003).

Robinson (2009) illustrates the severity of the e-waste problem; one-hundred times more dioxins are released into the atmosphere in burning e-waste than in the burning of regular domestic waste, making it particularly harmful. The greatest global emission contaminant source from e-waste is the burning of copper wiring, responsible for 820,000 tons of emissions per year (Robinson 2009). The second most common source is nickel, typically from batteries, responsible for 206,000 tons of annual global e-waste emissions. The third is chromium, found in data tapes and floppy disks, responsible for 198,000 tons of annual global emissions.

As the awareness around the e-waste problem and its associated environmental impacts has grown, there has been a significant international push to address the issue through legislation. One of the earliest and most universal is the 1989 Basel Convention. The convention, with 188 countries as parties and 53 as signatories, regulates the transboundary movement of hazardous waste, including e-waste; specifically, the convention is aimed at controlling exports from developed nations to developing areas of the world. The Ban Amendment to this convention, proposed in 1995, would ban all e-waste transport from developed to developing countries, however, it has not yet been put into force [Iqbal et al., 2015; Davis et al., 2019]. Following this convention, countries that produce large amounts of e-waste have attempted to control the disposal of such waste by starting Extended Producer Responsibility (EPR) programs. These programs focus on the responsibility of producers to control the fate of waste after the production process; these can range from voluntary guidelines to mandatory legislation (Widmer, 2005). These efforts to control e-waste and its fate after the end of the usable lifespan does indicate a willingness of legislative bodies to attempt to address the problem. However, because many informal e-waste hubs deal with both foreign and domestic waste, simply controlling the movement of such waste does not adequately address all parts of the problem. In addition, measures such as the Basel Convention are very broad in language and have not been universally ratified, severely limiting the power of such legislation [Iqbal et al., 2015; Ni & Zeng, 2009].

The effective management of e-waste is challenging, but there is no general agreement on best practices. Some reports (Ni & Zeng, 2009) argue that weak regulations and inconsistent enforcement are the main culprit, and empowering and encouraging law enforcement to act against informal waste processing is the solution. However, more recently, there has been a growing recognition of the importance of these informal hubs on the livelihood of those involved with the industry. Many scholars are beginning to conclude that the correct path of action is to formalize the existing recycling industries, bolster the “reverse supply chains” in these countries, and push these sectors towards more environmentally safe practices [Davis et al., 2019; Widmer, 2005; Hilty et al., 2013; Awasthi et al., 2016]. Despite these disagreements on how to solve the e-waste problem, a theme that emerges whenever these informal hubs are studied is the clear and present need for more reliable and consistent data about the informal e-waste management practices.

In the past decade, there have been increasing efforts to monitor e-waste burning, especially in the informal sector where there is less easily accessible information. Several informal e-waste hubs in Ghana, Pakistan, and China became sites of interest to environmental researchers and activists because of the danger posed to large population centers and highly trafficked areas. For example, take the Agbogbloshie area of Accra, Ghana. The need for monitoring informal e-waste burning became prioritized by researchers in Agbogbloshie because of its proximity to one of the largest outdoor food markets in Ghana. Smoke from burning e-waste nearby poses health threats to people shopping or working at the market (Boye-Doe, 2019). In Pakistan, the largest e-waste recycling sites are in and around the larger cities of Lahore, Faisalabad, and Karachi [Iqbal et. al, 2015; Sajid et al., 2019]. The locations of said sites encouraged research regarding local e-waste movement, but e-waste hubs in less prominent locations go overlooked and under-studied.

The main case study of our report centers around a particular informal e-waste hub that has appeared in the West Line villages in southwest Hebron, West Bank (Figure 1).

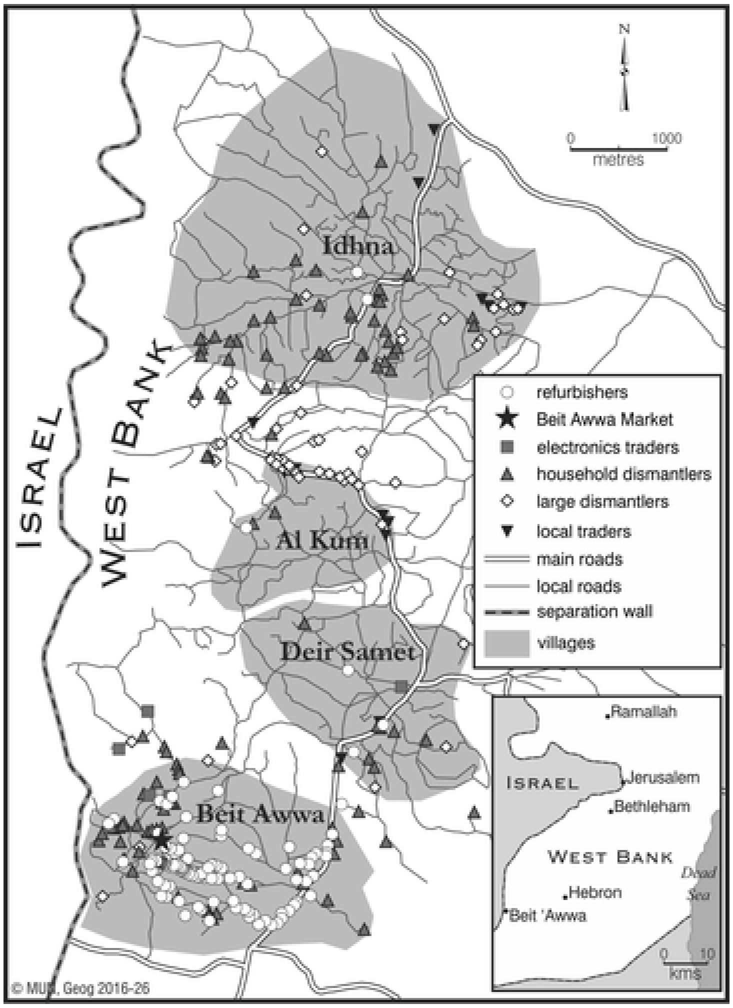

Figure 1: E-waste dependent businesses in the West Line (Davis and Garb, 2019b).

Over the past two decades people in the four villages of Idhna, Al Kum, Deir Samet, and Beit Awa, as well as the hills surrounding the area, have regularly seen clouds of dense black smoke (Figure 2) fill the sky as cables are sporadically burned to extract the copper within. (Davis & Garb, 2019b).

Figure 2: Smoke from an e-waste burn in the West Line villages (Yaakov Garb, 2020).

Palestinian junk collectors from the West Bank buy (or collect for free) discarded materials including e-waste from Israel and transport it to the West Line villages, where between 7 and 35 tons of copper wires are burned daily (Davis & Garb, 2015).

The emergence of e-waste burning as an important economic sector in the West Line can be linked to high unemployment rates in Palestine. Most of the Palestinian workforce, especially prior to the Second Intifada, was dependent on work in Israel throughout the 1980's and 90's (Roy, 1999). After the Second Intifada, Israel placed restrictions on Palestinians which made it harder for them to get access to work in Israel, raising unemployment rates in the West Bank. From 2000 to 2015, the unemployment rate never dropped below 12.2% (where it had been in 2000), reaching a high of 28.2% in 2002. Since 2009, it has remained steadily high, fluctuating between 19.7% and 17.3%. In 2018, the rate was reported to be 18% (Regional Office for Arab States 2018; *Labour Force Survey*, 2019). The occupation of Israeli forces in the West Bank in tandem with an increasingly strained economy left many in desperate need of an income, and informal e-waste burning sites began appearing. With the agricultural landscape creating sufficient space for open burning and a pre-existing tradition of refurbishing used items, the West Line became a hotspot for burn sites, leading to an unregulated and influential e-waste industry being established in the villages over the next two decades (Davis et al., 2019).

Since this e-waste hub, like those discussed previously, is informal, income is not reported. This leaves governments ignorant on the severity of the situation (Davis & Garb, 2019b). Despite this, e-waste recycling is tightly tied to the economy of the West Line Villages. Between 2000 and 2015 e-waste processing became the leading economic influence in the area, providing income to approximately 1,098 people in 2015 (Davis & Garb, 2019b). Surveys of burners conducted by Davis and Garb (2019b) revealed that somewhere between 16,000 and 25,000 tons of e-waste were processed and collected in 2015, adding 28.5 million USD to the economy in Palestine. While this study was being performed, the e-waste hub was performing at 60% of the capacity of the previous decade, due to new government regulations, indicating that the economic impact of the industry was likely underestimated and could be much greater. In a report to the Palestinian government, the non-governmental organization ARIJ estimated that between 200- 250 tons of e-waste came into Idhna daily (The Applied Research Institute Jerusalem, 2015). This is equal to 1 billion NIS (approximately 264 million USD) annually. However, Davis and Garb (2019b) questioned the validity of this estimate, noting that this was equivalent to the upper estimate for e-waste generated in Israel daily.

The relationship between the authorities responsible for apprehending burners and the citizens who report burns is subject to pitfalls due to the challenges included in the reporting process. Often, it can prove difficult for authorities to respond in time before the conclusion of a burn; cable burning can be finished as quickly as 20-30 minutes (Davis and Garb, 2020). Additionally, e-waste burning is a daily occurrence, and police that arrive too late to burn sites lose motivation to respond to new reports (Davis and Garb, 2020). Although we focus on issues specific to the West Line villages, it is obvious that e-waste burning can be partially attributed to intervention from authorities. There is no real means of testing the accuracy of burn prevention measures, including NGOs or community policing efforts. Burn sites, burners and the amount of material burned has never been tracked, thus there is no baseline to compare new information to.

To motivate residents to get involved in reducing e-waste, Davis and Garb (2020) conceptualized and tried a model of community policing involving reporting burns to response units that would drive to the burn site. This method was effective in reaching the burn sites while the burns were active, with an 85% success rate. With this observed success, they attempted to set up a continuation of that system with the Palestinian Authority, the Environmental Quality Authority, and the local authorities in the West Line to curb the burning. However, because of the political tensions and unwillingness of each body to cede power to the others, the funding, and resources to allow the system to function were withheld. With a consistent record of burning activity, the residents will have more evidence to lend power to their case. In the same paper, Davis and Garb noted a model of "active" and "passive" community environmental policing. Active policing includes data collection/environmental violations monitoring, analysis of these violations to influence informed policy changes and developing a course of action to overcome pre-existing barriers for policing the environment. This varies from passive community environmental policing which relies solely on data collection and environmental monitoring, reporting the violations, and then supporting government enforcement of environmental violations. While some of this model relies on the action and mobilization of a motivated community, it is important to note that the foundation of this model is a strong monitoring and documentation system.

Burn site reporting currently happens through two WhatsApp groups curated by Professor Garb. One of these groups allows for Israelis to report burns, while the second group exists for reports from the Palestinian side. The Israeli group was created spontaneously by a resident of a neighboring village. In general, the goal of the Israelis in this group is for the burners to be apprehended by law enforcement. However, the residents on the Palestinian side of the border do not share this goal, and would rather address the environmental issues of the e-waste industry without the use of force and the loss of livelihood that would be associated with the law enforcement solution. These WhatsApp groups allow members of the local community to share images of different burns. The platform also allows discourse between each of the members, creating a sense of community. There are a few downsides to this platform; the data has no public access, which limits the incoming reports to only the members of the WhatsApp group, and the only data that is being reported to the government and recorded in an official capacity is the data from the Israeli WhatsApp group. In addition, manual reporting systems in general have certain limitations that leave gaps in our knowledge. Most of these limitations stem from the reliance of the manual reporting system on human involvement. If manual burn reporting is the only option, the data collected is limited to what the small group of reporters notices and has time to document. This places a considerable burden of vigilance on the residents and is not sufficient to monitor all burn activity. These gaps motivated us to create a publicly accessible system that compiles the data of burn sites in one cohesive database.

There are many platforms that can be used to upload and record data. Practically, these can look like applications available for download, forms for submission, and text chats, although these options are not all-inclusive. Liu et al. (2021) discuss practical examples of the infrastructure of citizen science, from which good practices are identified as the creation of such infrastructure. Contributors should feel that they have partial ownership and responsibility over the efforts being made and that they are working together to establish collaborative governance: where an ongoing issue is continually dealt with by members of those affected. Organizations such as local communities often turn to collaborative governance because other strategies fail (Ansell et al, 2018). This can be seen in the case of the West Line, where these unofficial groups have formed due to a lack of official action.

To improve current e-waste burn tracking methods in the West Line villages, we developed a streamlined burn site reporting system and an image processing program to monitor time lapse footage of burn sites. The improved burn reporting system is available through a website (https://ewasteburning.wixsite.com/beitawa) where information from burn site reports is stored in hopes of maintaining long term records of burns. We hope to make it easier to report burns, thus improving the amount of burns that are detected by this manual system. In contrast to the improved reporting system that requires manual submissions, our image processing software aims to monitor burn sites with as little human interaction as possible. The image processing program collects images from a time lapse of the horizon over an area with frequent burn sites and confirms the presence of burns based on the duration and amount of smoke captured.

Methods

Our project addresses the lack of reliable information on e-waste burning in the West Line in two ways: first, we support the current process of photographing and reporting burn events by making the reporting process more accessible and keeping records of the data. Second, fill the gaps in the current reporting process by creating an automated burn detection system, reducing the burden of human vigilance while improving the overall knowledge about e-waste burn events. To ensure our project is well received, we adhere to the guiding principles of citizen science (Robinson et al., 2018), which assert that participants in citizen science must receive feedback and updates on the progress of the research, and that data from the research must be openly accessible where possible. To comply with these guidelines, our initiative to track the size, duration, and frequency of e-waste burning must also publish the results, as frequently and transparently as possible.

Streamlined Burn Reporting System

By designing a website to allow easy documentation and reporting of burns, as well as publicly viewable data from this reporting, we created a platform for collective efforts to improve documentation of burn events. We created the website through the website builder Wix and embedded a third-party form using a resource called Jotform. Via Jotform, we asked single choice questions including the option to upload a picture of the burn and record the precise location of a burn. This provided a coordinate reference to where the user is located when reporting the burn site. We integrated a separate Google Sheet to the Jotform platform so that the incoming data can be transferred to one spreadsheet. In addition, a mini report with the pictures and entries is automatically generated in said Google Drive. All the data are compiled into one spreadsheet, where graphs are generated to display the data. These graphs created a publishable link which was embedded into the website to allow users to view the incoming data real time. We formed a document with a set of questions and key phrases that would be used on the website, form, and graphs. The document was translated into Hebrew, making it accessible to the local Israeli community as requested by Professor Garb for trials among Israeli burn reporters. In the future, we propose making the burn reporting site accessible to Palestinian citizens on the West Bank by offering an Arabic version as well.

Monitoring Burn Sites with Image Processing

As a supplementary burn monitoring method, we explored computer vision programs to create an automated smoke detection system. An image can be analyzed via pixel colors and brightness to determine shapes, sizes, and relative location of objects within said image. Some algorithms for fire detection use temporal difference of pixel brightness to identify when a fire starts by detecting actual flames (Hwang and Jeong, 2016). Monitoring smoke, however, is an effective way to track fires, as smoke can be visible for miles. Smoke is typically the first indication of an e-waste burn event, and due to the fluctuation in location and time, monitoring specific burn sites themselves is not as feasible as tracking smoke. Hwang and Jeong implemented color and behavior-based smoke detection software, which proved more effective than temporal fire detection. Smoke moves upwards from fires, and contrasts sharply against the color of the sky, thus motion and color can be predicted and tracked more effectively than fire itself (Hwang and Jeong, 2016). Furthermore, smoke detection AI has been utilized by The Institute of Electrical and Electronics Engineers (IEEE) as a preventative fire protection measure. Smoke occurs before a fire and can be tracked without complicated sensors (Turgay et al, 2007).

We began prototyping smoke detection strategies in ImageJ, where an image is first converted to greyscale by averaging the brightness of each pixel in each red, green, and blue layer to create a grayscale copy. The greyscale image is converted to binary, thus creating a black and white image (Figure 2).

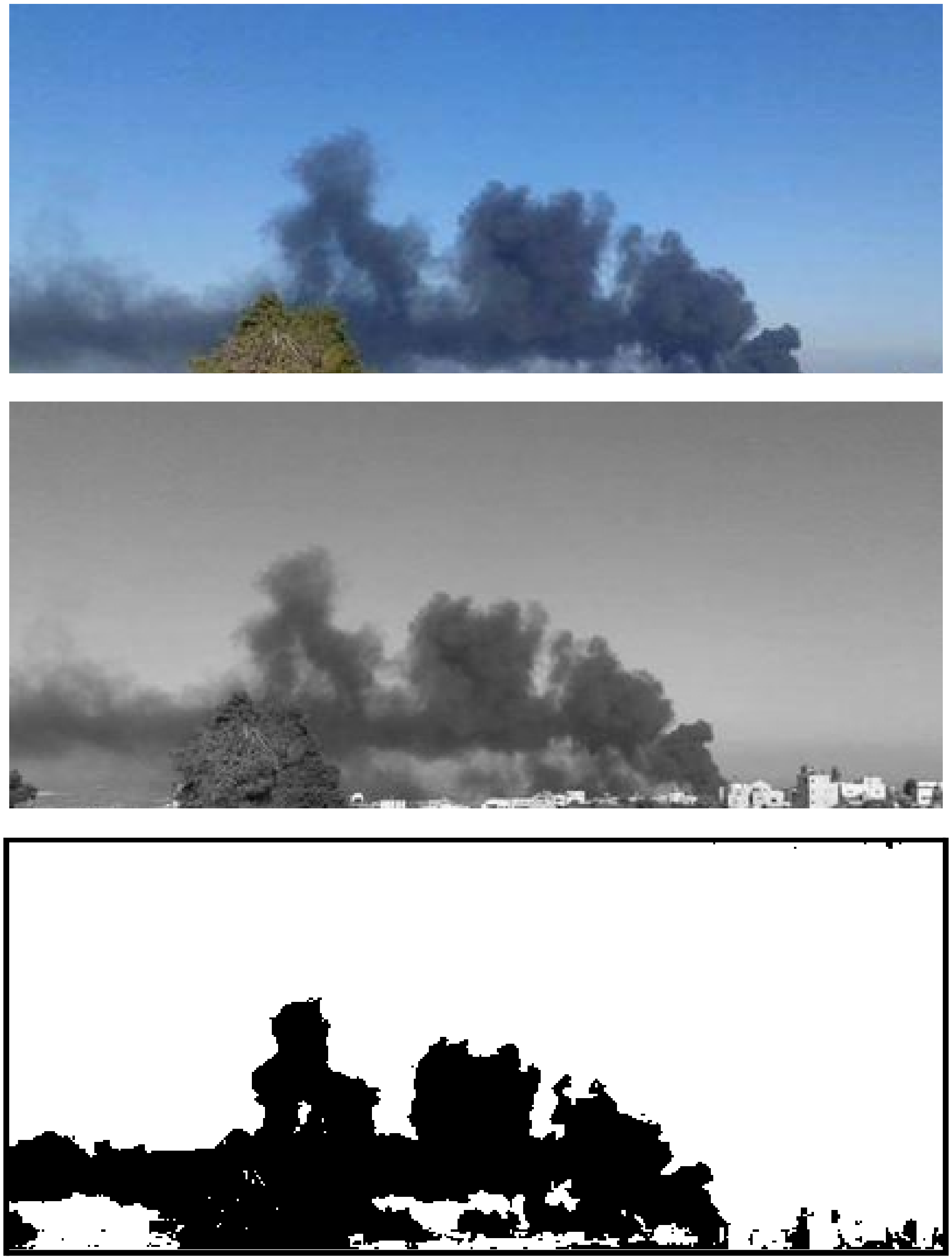

Figure 3: ImageJ color to binary conversion.

Smoke is depicted in black and stands out against the sky depicted in white. The black and white image particles can then be analyzed by pixel mass to indicate a burn event. We set a minimum pixel group to 100 pixels, which highlights groups of 100 or more black pixels, thus confirming smoke plumes from an e-waste burn site. The number of pixels indicative of smoke is exported to an excel sheet which confirms the size of a smoke plume, and the number of frames smoke appears in (Appendix B). Although tracking binary images of smoke never produced an accurate algorithm for smoke detection, image conversion methods as described above were applied to the final program. To process footage of burn sites, we wrote a script in python using the OpenCV library. The script performs the following steps on each frame in sequence: resize to 450 pixels to reduce processing requirements; convert to Hue-Saturation-Value (HSV) color space; define the color range that represents smoke; applies a black mask to the pixels that fall within that color range; counts the black pixels; saves the frame with a unique and sequential filename; sorts into one of two folders. These folders are either “empty”, meaning that no black pixels are present that indicate smoke, or “smoke”, meaning that black pixels, or the presence of smoke, has been detected. Because each frame corresponds to a certain amount of time based on time lapse requirements, the amount of time that smoke was present in the sky is determinable.

The code was built and refined using a gallery of 29 sample images taken on the Israeli and Palestinian sides of the West Bank border, each including a plume of smoke from a burn event. The code was later tested on time lapse footage captured from a hill overlooking the West Line, however, the 101 seconds of footage (representing around an hour and a half of real time) did not capture a burn event. It was useful as a control test, to ensure that the sensitivity of the image detection code was high enough to differentiate between storm clouds and smoke. The final test was run using 60 frames from a video that included, at various times, clear sky or plumes of smoke.

Results and Discussion

Through rigorous testing of our systems we were able to analyze the effectiveness of both our website and the image processing software. When tested, the image processing software correctly identified 100% of burns in the time lapse footage. However, there was a significant false-positive rate, with 71% of empty images being incorrectly sorted into the smoke category. The accuracy of this software could be improved by fine tuning the color boundaries further, or applying pre-processing to the frames to adjust contrast, brightness, cropping, or other factors of the image that may make the smoke easier to detect. This fine-tuning would require a significantly larger set of images to ensure accuracy. It is worth noting that the software was built using images from many different locations and views, and it could also be specifically tailored to a predetermined camera placement. These location-specific edits would improve the accuracy of the image detection in that unique case but would decrease its general applicability. In this way, the script in its current form represents a flexible baseline that can be adapted to fit a variety of needs including different landscapes and weather patterns both in Palestine and the rest of the world.

A drawback is that the process currently requires human intervention at several steps: someone must upload the time-lapse footage each day, and counting the burns detected by image processing must currently be done manually. These steps of uploading footage and quantifying the detected burns could, in theory, also be autonomous. However, this requires further research and development. This is recommended as a potential next course of action if this project is to be continued and applied to more real-world scenarios.

Our proposed image detection system is not effective at night. Because of the lack of ambient lighting at night and the resulting low brightness and noise in captured images the image processing pipeline described here would fail to distinguish smoke clouds reliably. Detecting more than daytime burns conceivably could be done, however, this would require more advanced cameras with thermal imaging or night vision technologies, which is significantly more expensive. Utilizing this monitoring and logging system may provide valuable insight into daytime burn trends at informal e-waste hubs but should not be used to determine a holistic picture of e-waste burning where night burning is a significant factor.

The website underwent a series of tests that collected a range of submissions. Each of the submissions differed from one another to add diversity in our data. The location is successfully entered in latitudinal and longitudinal coordinates into a spreadsheet. Once these coordinates are automatically entered, someone will have to go into the spreadsheet and manually copy these coordinates into a browser or mapping system to determine the specific location. If the user does not allow the location to be accessed, then no coordinates will be entered. The data also is generated automatically into a form on a Google Drive that includes any entry and pictures that were submitted. However, with the website there are some drawbacks. Considering that the reporting is based on human involvement, there is no automation to detect these burnings. Rather, the reporting is dependent on the involvement of the community and whether a mobile device is readily available at the time of sighting.

This process can be applied to other e-waste hubs worldwide and may find effective use in areas that seek to reduce e-waste burning. The informal e-waste hub in Agbogbloshie is a strong candidate due to the consistent frequency of burns in one set location. By using our proposed camera and detection setup focused on the horizon over the burn sites adjacent to the market in Agbogbloshie, a team could conceivably capture burn frequency data in the same manner as in the West Line Villages. Because of differences in weather patterns and local conditions, as well as different use of low-cost technology, adjustments in the autonomous detection setup may have to be made, yet the recorded footage would likely prove effective in e-waste environments in Agbogbloshie and worldwide.

Conclusion

Informal e-waste hubs are a complicated issue with detrimental effects on human health and the environment. An effective initiative that prevents sporadic non-point source burning and addresses the complicated economic and political dynamics in the sector would be ideal, however it is impossible to test its effectiveness without a baseline source of information on burning activity levels.

To determine the frequency of burns, we created a two-part system which uses image processing technology as well as a website user interface which collects citizen documented reports. This system will help provide insight to possible burning patterns in the West Line Villages, allowing for easier burn tracking. This project applies citizen science research and principles to the ongoing issue of e-waste burning in the West Bank. These tools can be potentially applied to other e-waste hubs worldwide, adding a valuable source of information to the conversation about e-waste management.

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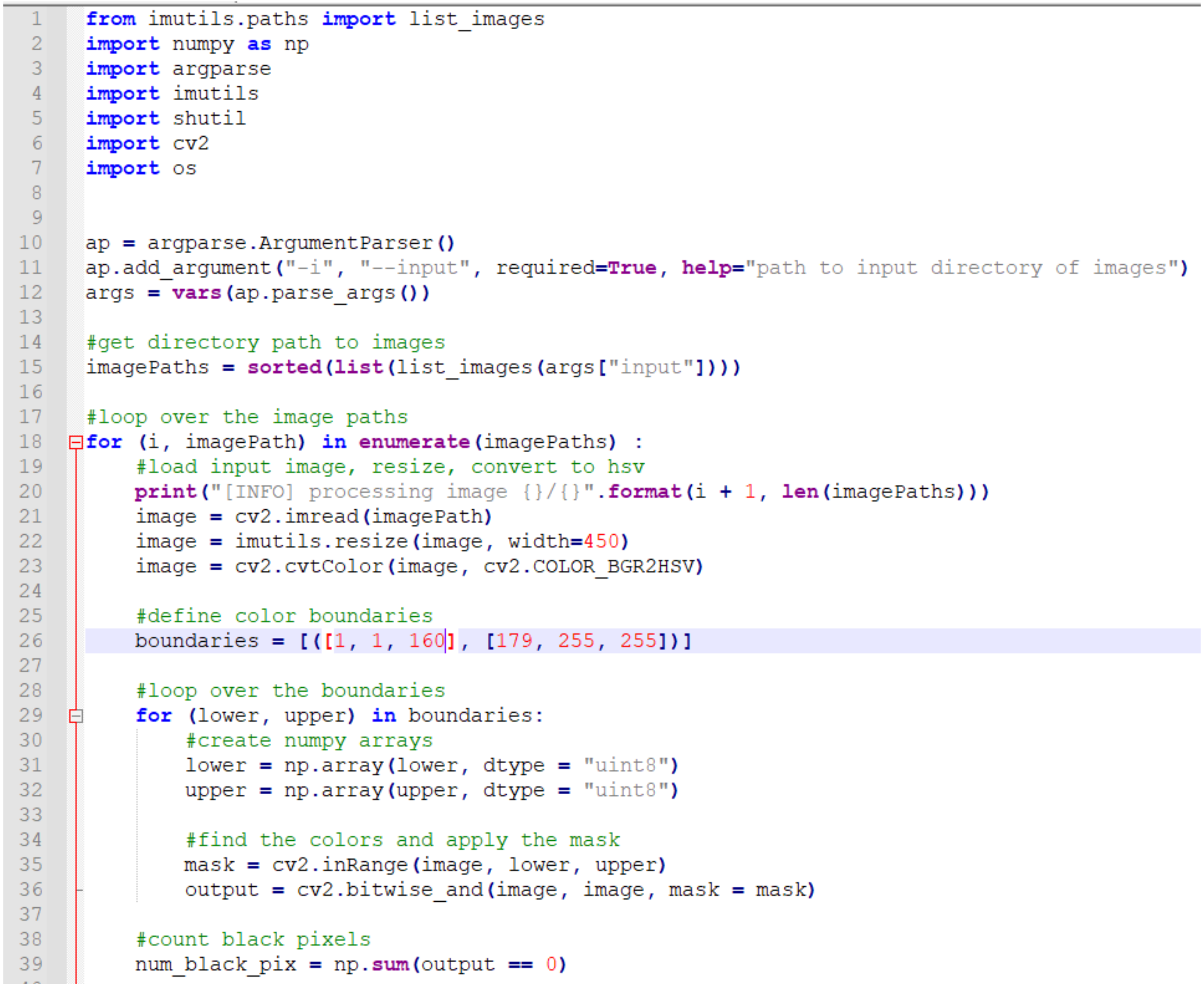
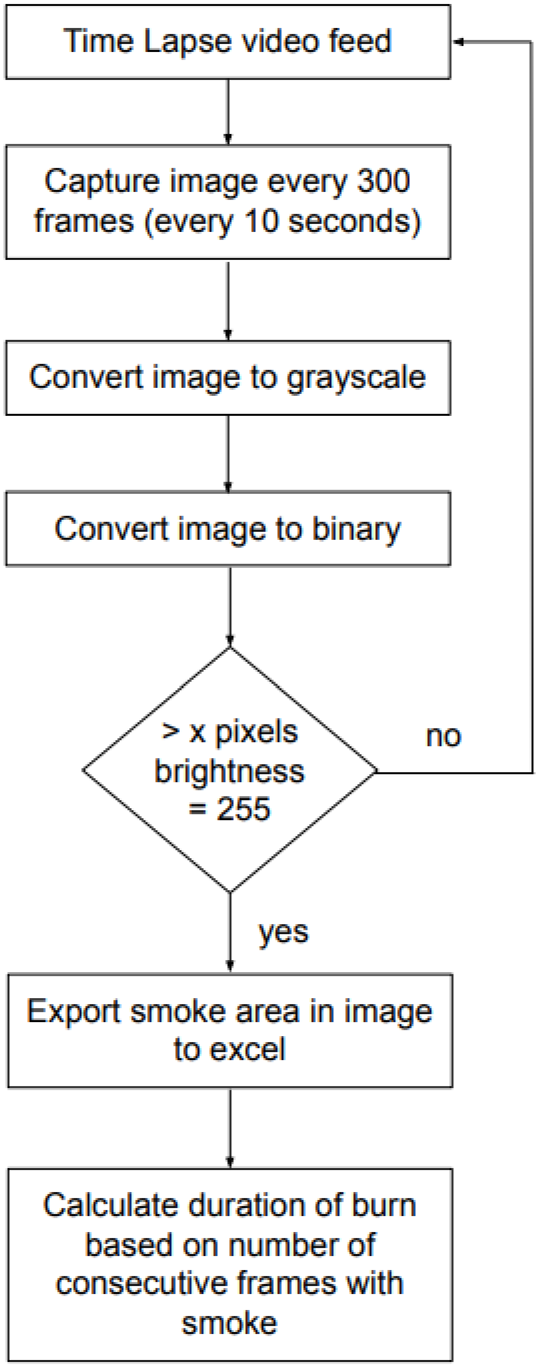
Appendix A: Python code



```python
from imutils.paths import list_images
import numpy as np
import argparse
import imutils
import shutil
import cv2
import os


ap = argparse.ArgumentParser()
ap.add_argument("-i", "--input", required=True, help="path to input directory of images")
args = vars(ap.parse_args())

#get directory path to images
imagePaths = sorted(list(list_images(args["input"])))

#loop over the image paths
for (i, imagePath) in enumerate(imagePaths) :
    #load input image, resize, convert to hsv
    print("[INFO] processing image {}/{}".format(i + 1, len(imagePaths)))
    image = cv2.imread(imagePath)
    image = imutils.resize(image, width=450)
    image = cv2.cvtColor(image, cv2.COLOR_BGR2HSV)

    #define color boundaries
    boundaries = [([1, 1, 160], [179, 255, 255])]

    #loop over the boundaries
    for (lower, upper) in boundaries:
        #create numpy arrays
        lower = np.array(lower, dtype = "uint8")
        upper = np.array(upper, dtype = "uint8")

        #find the colors and apply the mask
        mask = cv2.inRange(image, lower, upper)
        output = cv2.bitwise_and(image, image, mask = mask)

    #count black pixels
    num_black_pix = np.sum(output == 0)
```

```python

    #show the images
    cv2.imshow("image", np.hstack([output]))
    cv2.waitKey(0)

    #save processed images
    i += 0
    cv2.imwrite('C:/Users/max12/documents/processed%s.jpg' % i, output)

    #move empty images to correct folder
    if num_black_pix == 0:
        shutil.move('C:/Users/max12/documents/processed%s.jpg' % i, 'C:/Users/max12/Documents/python/output/empty')
        continue

    #move smoke images to correct folder
    shutil.move('C:/Users/max12/documents/processed%s.jpg' % i, 'C:/Users/max12/Documents/python/output/smoke')

```

Appendix B: ImageJ/Java Flowchart



Appendix C: Data Display from Website