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Cyber Security Research Center

Lamphone

Passive Sound Recovery from a Desk Lamp's Light Bulb Vibrations

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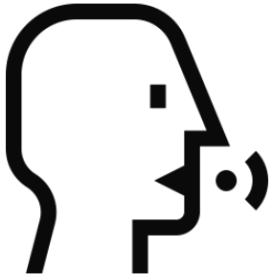
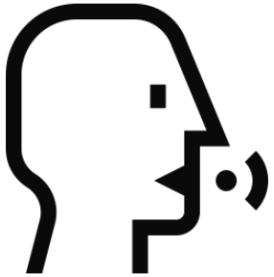
מכון ויצמן למדע
WEIZMANN INSTITUTE OF SCIENCE

A Light Bulb as a Microphone?



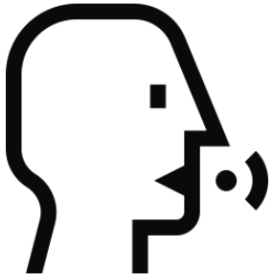
- Research Question: Can a desktop bulb be used as a microphone?

A Light Bulb as a Microphone?



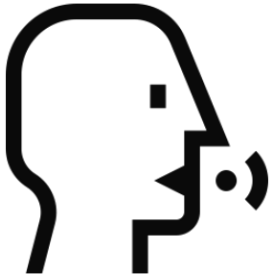
- Research Question: Can a desktop bulb be used as a microphone?
- Answer: By using scientific tools to analyze the vibrations of a light bulb, attackers can recover high quality speech and non-speech audio.

A Light Bulb as a Microphone?



- Warning: Turning a light bulb into a microphone is challenging.

A Light Bulb as a Microphone?



- Warning: Turning a light bulb into a microphone is challenging.
- Primary reason: Light bulbs were not designed to be used as microphones.

Related Work

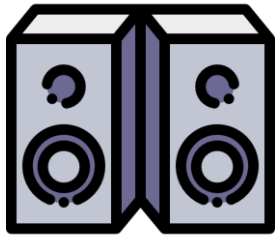
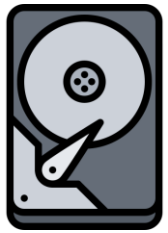
Related Eavesdropping Research

- In recent years, **various non-acoustic** eavesdropping methods have been developed by the scientific community.
- These methods can be divided into two main categories.

Limitations of Existing Methods

Internal Methods

Motion Sensors **Output Devices** **Misc.**

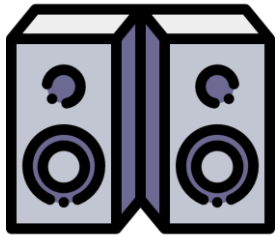
Methods which obtain data by using a device located in proximity to a target

Limitations of Existing Methods

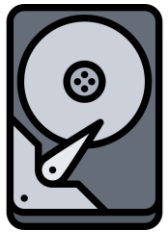
Internal Methods

Motion Sensors

Output Devices



Misc.

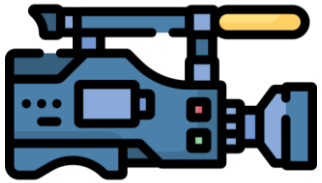


Methods which obtain data by using a device located in proximity to a target

External Methods

Laser Microphone

Visual Microphone



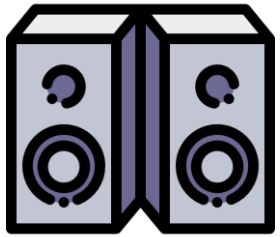
Methods that rely on data obtained by a device that is not located near a victim

Limitations of Existing Methods

Internal Methods

Motion Sensors

Output Devices



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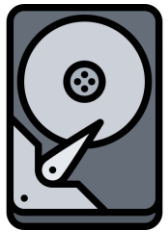

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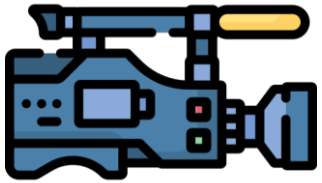


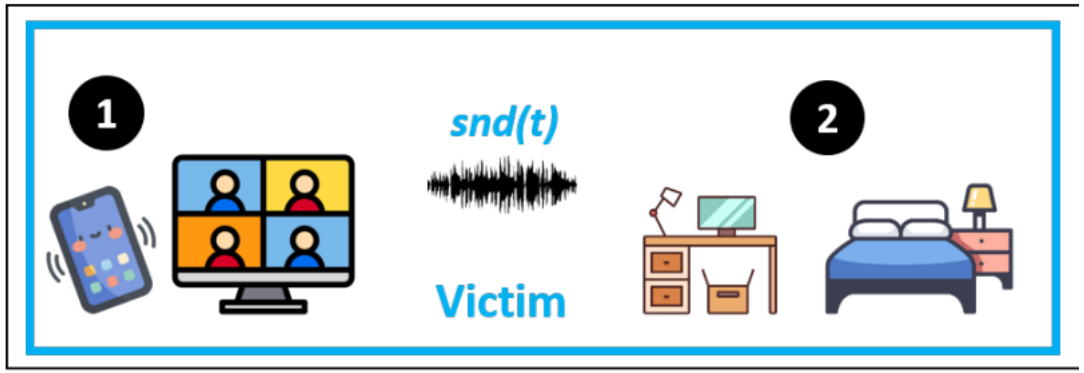
Each method is limited by one of the following:

- Some methods require the attacker to compromise a device with a malware
- Some methods are active - which makes it easier for the victim to detect the use of the method
- Some methods cannot be applied in real time - because they require heavy computational resources
- Some methods are limited at recovering speech at scream levels (> 85 dB)

Lamphone's Threat Model

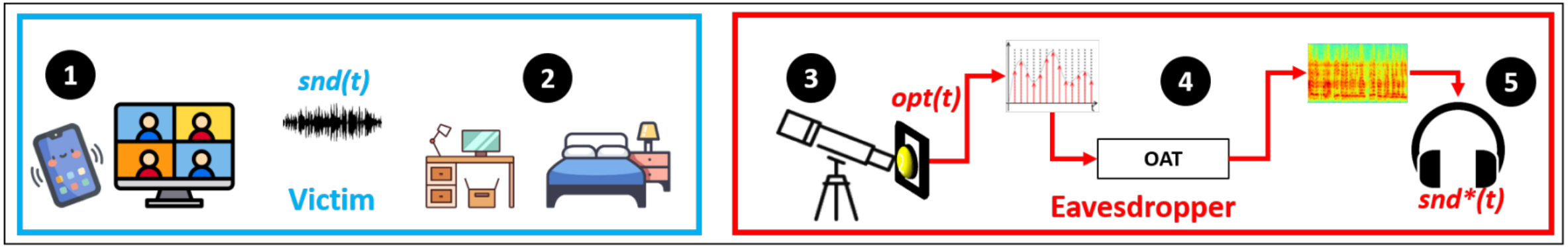
Lamphone's Threat Model

- The sound snd(t) from the victim's room (1) creates fluctuations on the surface of the desk lamp's light bulb (the diaphragm) (2).



Lamphone's Threat Model

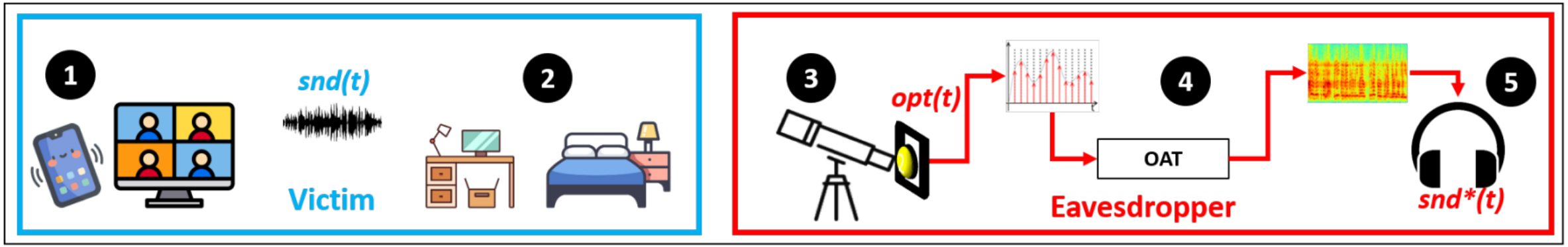
- The eavesdropper directs an electro-optical sensor (the transducer) at the light bulb via a telescope (3).
- The optical signal opt(t) is sampled from the electro-optical sensor via an ADC (4) and processed, using an algorithm to recover the acoustic signal snd∗ (t) (5).



Lamphone's Threat Model

From eavesdropper's perspective Lamphone attack is

- **External** (does not rely on a compromised device).
- **Passive** (does not give an indication regarding its use).
- Can be applied in **real time**.
- Can recover speech in **normal volume levels** (~75 dB).



Physical Analysis

The Physical Phenomenon

- Sound waves (speech) hit the light bulb’s surface.

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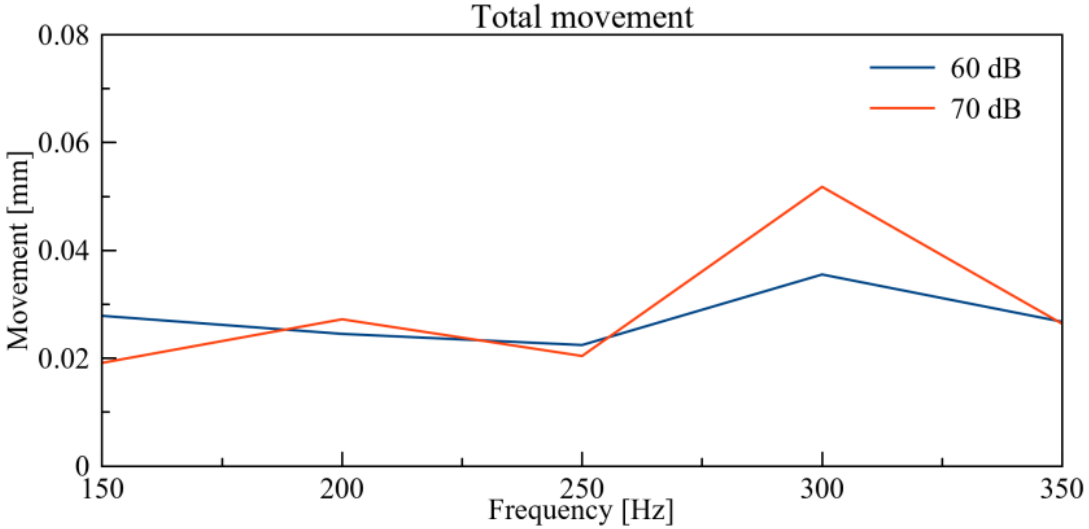
- The light bulb vibrates according to the sound wave (the vibrations modulate the speech\sound) and turns into a **diaphragm**.

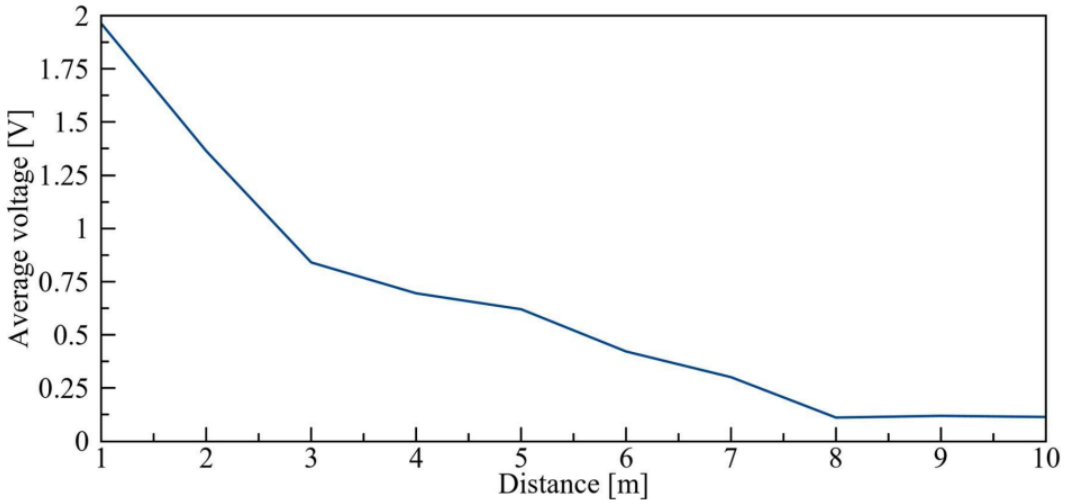
The Physical Phenomenon

- The light bulb's vibrations create very small changes in the distance between the light bulb and a static photodiode (17-55 microns).



The Physical Phenomenon

- The small changes in the distance between the surface of the bulb cause the photodiode to output different voltage levels (which serve as optical measurements).



The Physical Phenomenon

- The small changes in the distance between the surface of the bulb cause the photodiode to output different voltage levels (which serve as optical measurements).
- The optical measurements modulate the sound near the light bulb (with some additional side effects).

The Physical Phenomenon

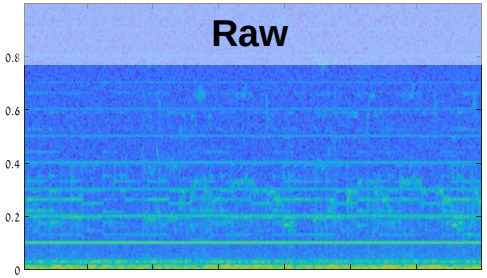
- The small changes in the distance between the surface of the bulb cause the photodiode to output different voltage levels (which serve as optical measurements)

The analysis in the paper shows how to determine the sensitivity of the equipment that is needed to recover speech based on the distance between the eavesdropper and the light bulb.

Optical Acoustical Transformation (OTA) Algorithm

OAT Algorithm

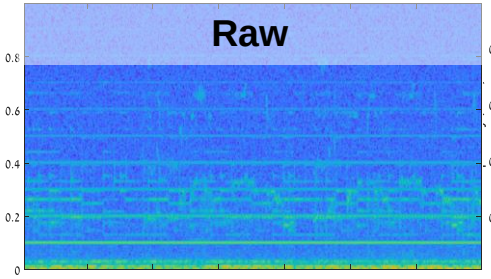
To reconstruct sound from the sampled optical signal, the digital data must be filtered from unwanted interferences. In order to do so, the sampled data was processed in the following stages:

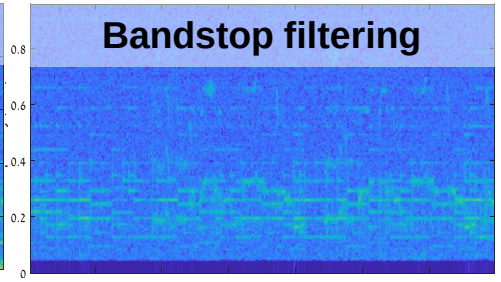


OAT Algorithm

To reconstruct sound from the sampled optical signal, the digital data must be filtered from unwanted interferences. In order to do so, the sampled data was processed in the following stages:

- Filtering using band-stop and high-pass filters

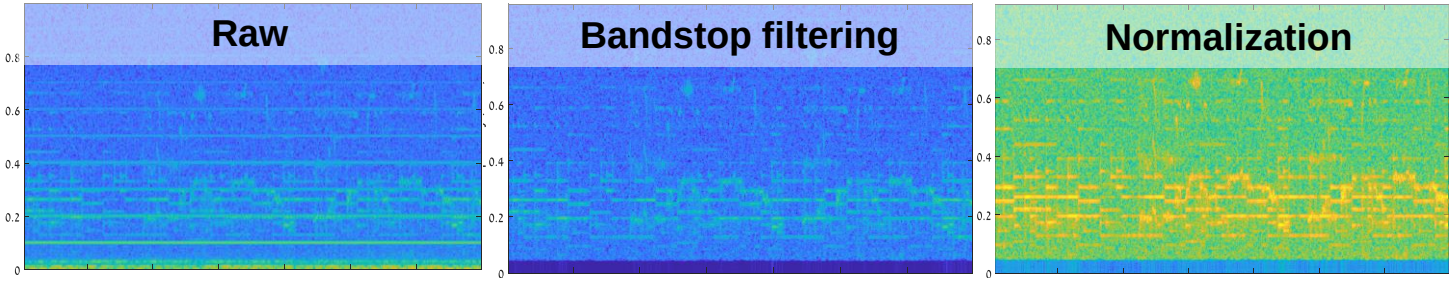




OAT Algorithm

To reconstruct sound from the sampled optical signal, the digital data must be filtered from unwanted interferences. In order to do so, the sampled data was processed in the following stages:

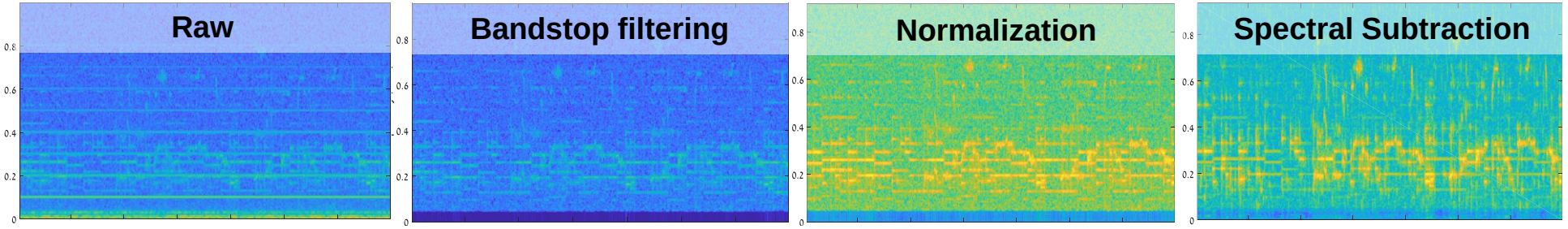
- Filtering using band-stop and high-pass filters
- Normalization



OAT Algorithm

To reconstruct sound from the sampled optical signal, the digital data must be filtered from unwanted interferences. In order to do so, the sampled data was processed in the following stages:

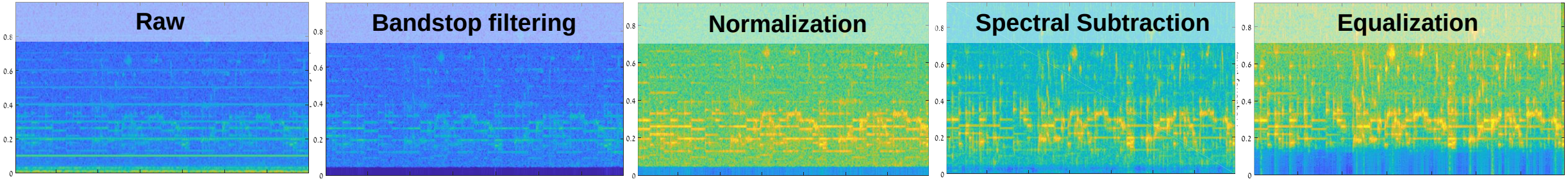
- Filtering using band-stop and high-pass filters
- Normalization
- Spectral Subtraction



OAT Algorithm

To reconstruct sound from the sampled optical signal, the digital data must be filtered from unwanted interferences. In order to do so, the sampled data was processed in the following stages:

- Filtering using band-stop and high-pass filters
- Normalization
- Spectral Subtraction
- Equalization

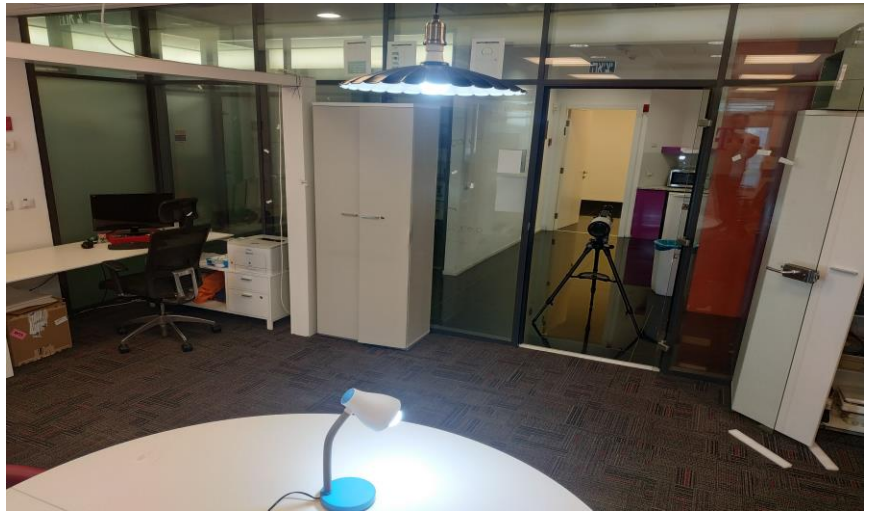


Evaluation

Comparison to Visual Microphone

We replicated “Visual Microphone” setup:

- An illuminated table lamp was placed in the office.
- Six sentences from **TIMIT database** were played (as in VM).
- The speech level that was used is **95dB** (as in VM).
- The optical measurement were obtained from **3 meters away** (as in VM).
- We placed the speakers **5 cm** away from the light bulb (as in VM).



Comparison to Visual Microphone

	Speech	Intelligibility		LLR		WSS		NIST STNR	
		VM	Table lamp	VM	Table lamp	VM	Table lamp	VM	Table lamp
Female speaker - fadg0, sa1	"She had your dark suit in greasy wash water all year"	0.72	0.72	1.47	1.79	120.2	75.55	26.8	16
Female speaker - fadg0, sa2	"Don't ask me to carry an oily rag like that"	0.65	0.67	1.37	2.1	197.8	71.76	43.3	4.5
Male speaker - mccs0, sa1	"She had your dark suit in greasy wash water all year"	0.59	0.7	1.31	1.72	149.5	63.1	27.3	10.3
Male speaker - mccs0, sa2	"Don't ask me to carry an oily rag like that"	0.67	0.71	1.55	1.86	137	59.23	18	2.8
Male speaker - mabw0, sa1	"She had your dark suit in greasy wash water all year"	0.77	0.67	1.68	1.48	211. 1	54.97	6	5.5
Male speaker - mabw0, sa2	"Don't ask me to carry an oily rag like that"	0.72	0.69	1.81	1.89	162.1	73.77	25.8	5.3
	Average:	0.68	**0.69**	**1.53**	1.8	162.9	**66.39**	**24.5**	7.4

Original Recovered

Original Recovered

Comparison to Visual Microphone

Conclusion:

The quality of the recovered speech by Lamphone and the visual microphone is at the same level.

The influence of the Distance on Lamphone's Performance

In the next experiment we tested our ability to recover audio from various distances. The following setup was used:

- An illuminated table lamp was placed in the office.
- The speakers were set to output sound at a volumes of **75 dB**.
- A famous statement made by Donald Trump was played inside the office:
  - "We will make America great again!"
- Measurements were obtained from various distances (**5m – 35m**) and signals were recovered.
- The speakers were placed **25 cm** away from the light bulb.

The influence of the Distance on Lamphone’s Performance

The influence of Sound Level and Distance on Lamphone's Performance

	Distance between electro-optical sensor and light bulb											
	15m				25m				35m			
Distance between speakers and light bulb	Intelligibility	WSS	LLR	NIST-SNR	Intelligibility	WSS	LLR	NIST-SNR	Intelligibility	WSS	LLR	NIST-SNR
25 cm	0.522	660.47	6.72	21	0.487	643.1	5.11	21.8	0.454	686.65	4.22	17.5
50 cm	0.457	669.37	3.5	12.3	0.4	651.16	4.34	21	0.362	635.9	3.75	11.5

The influence of Sound Level and Distance on Lamphone's Performance

Conclusion:

Perceptible speech can be recovered from a distance of 35 meters at experimental setup of a virtual meeting (75 dB) when the victim sits in front of a desktop in a distance of 25 cm from the light bulb (equivalent to half of the depth of a standard desktop).

Takeaways

Takeaways

- Takeaway 1: Smartphones and laptops pose a greater risk to individual's privacy than light bulbs.

- In this context, Lamphone is a calculated risk.
  A risk that should be taken into account only after you mitigated greater eavesdropping risks posed by Internet connected devices with integrated microphones (e.g., laptops and smartphones).

Takeaways

- Takeaway 2: Probably, Lamphone was utilized in the wild 30 years ago.

Question: What is the reason for this argument?

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Question: What is the reason for this argument?

Answer: **“The Thing”** a.k.a **“The Great Seal Bug”** - an eavesdropping device which was concealed inside a picture that was given as a gift for the US ambassador for the Soviet union.

Takeaways

- Takeaway 2: Probably, Lamphone was utilized in the wild 30 years ago.

Question: What is the reason for this argument?

Answer: “The Great Seal Bug”
is considered as the predecessor
of the RFID technology.

It was used by the Soviets to
eavesdrop speech around 1945 while
the RFID technology was patented in the US at 1973.

Questions

Thank you

Glowworm Attack – CCS 21

The Little Seal Bug – BH 22