Faculty of Electrical and Electronic Engineering Technology

DEVELOPMENT OF WEATHER INFORMATION SYSTEM USING NOAA SATELLITE DATA RETRIEVER SYSTEM WITH RTL-SDR

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

AFIQ BIN SHAHRULNIZAM

Bachelor of Electronics Engineering Technology (Telecommunications) with Honours

2022

DEVELOPMENT OF WEATHER INFORMATION SYSTEM USING NOAA SATELLITE DATA RETRIEVER SYSTEM WITH RTL-SDR

AFIQ BIN SHAHRULNIZAM

A project report submitted
in partial fulfilment of the requirements for the degree of
Bachelor of Electronics Engineering Technology (Telecommunications) with Honours

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Electrical and Electronic Engineering Technology

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2022

UNIVERSITI TEKNIKAL MALAYSIA MELAKA
FAKULTI TEKNOLOGI KEJUTERAAN ELEKTRIK DAN ELEKTRONIK

BORANG PENGESAHAN STATUS LAPORAN
PROJEK SARJANA MUDA II

Tajuk Projek : DEVELOPMENT OF WEATHER INFORMATION SYSTEM USING NOAA SATELLITE DATA RETRIEVER SYSTEM WITH RTL-SDR

Sesi Pengajian : SEMESTER 1 (2022/2023)

Saya Afiq bin Shahrulnizam mengaku membenarkan laporan Projek Sarjana Muda ini disimpan di Perpustakaan dengan syarat-syarat kegunaan seperti berikut:

1. Laporan adalah hakmilik Universiti Teknikal Malaysia Melaka.
2. Perpustakaan dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan laporan ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. Sila tandakan (✓):

☐ **SULIT*** (Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia seperti yang termaktub di dalam AKTA RAHSIA RASMI 1972)

☐ **TERHAD*** (Mengandungi maklumat terhad yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan)

☑ **TIDAK TERHAD**

Disahkan oleh:

(TANDATANGAN PENULIS)

(COP DAN TANDATANGAN PENYELIA)

Alamat Tetap: B-14-11 PANGSAPURI SRI PENARA, NO 6 JALAN SRI PERMAISURI 1, BANDAR SRI PERMAISURI CHERAS, 56000 KUALA LUMPUR, W. PERSEKUTUAN (KL)

DR. NOR AZLAN BIN MOHD ARIS
Pensyarah Kanan
Jabatan Teknologi Kejuruteraan Elektronik dan Komputer
Fakulti Teknologi Kejuruteraan Elektrik dan Elektronik
Universiti Teknikal Malaysia Melaka

Tarikh: 17/02/2023

Tarikh: 17/02/2023

*CATATAN: Jika laporan ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali tempoh laporan ini perlu dikelaskan sebagai SULIT atau TERHAD.

DECLARATION

I declare that this project report entitled "Development of Weather Information System using NOAA Satellite data Retriever system with RTL-SDR" is the result of my own research except as cited in the references. The project report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :

Student Name : AFIQ BIN SHAHRULNIZAM

Date : 17 February 2023

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

APPROVAL

I hereby declare that I have checked this project report and in my opinion, this project report is adequate in terms of scope and quality for the award of the degree of Bachelor of Electronics Engineering Technology (Telecommunications) with Honours.

Signature : ....

Supervisor Name : DR. NOR AZLAN BIN MOHD ARIS

Date : 17 February 2023

Signature : ....

Co-Supervisor Name (if any) : ....

Date : ....

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

DEDICATION

Special dedication to my beloved parent,

SHAHRULNIZAM BIN ABU BAKAR

And

ZALIZAH BINTI MD NOR

My lovely sister

AFIQAH BINTI SHAHRULNIZAM

My supportive and kind hearted Supervisor

DR. NOR AZLAN BIN MOHD ARIS

UTeM
اونيۏرسيتي تيكنيكل مليسيا ملاك
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

ABSTRACT

Polar meteorological satellites such as the NOAA satellite is one of the most important environmental information sources regarding the Earth and atmosphere. It is administered by the NOAA (National Oceanic and Atmospheric Administration) administration in the United States to provide live images of Earth through radio, which is received by users on the ground. However, access to weather satellite image data in real-time is limited due to several factors such expensive development cost for a receiver system, and lack of expertise to decode the hidden information contained in it and are still considered a major issue faced by satellite enthusiasts. Therefore, the purpose of this project includes creating a prototype of a ground station capable of completing this duty and documenting the whole process. RTL-SDR could be one of the alternatives that is cheaper and assist enthusiasts to explore this RTL-SDR deeper. This project utilizes software and hardware component such as WXtoImg, SDRsharp, Antenna and RTL-SDR to receive the data from the satellite. The RTL-SDR chosen to use in this system will be RTL-SDR 2832U. The software used in this project is WXtoImg for generating images and SDRsharp as integration with RTL-SDR to process data from an antenna. In this project, the result shows the image of earth which was displayed by laptop. In conclusion, this project has been successfully developed as a weather information system and able to generate weather images using the NOAA satellite data receiver.

ABSTRAK

Satelit meteorologi kutub seperti satelit NOAA adalah salah satu sumber maklumat alam sekitar yang paling penting mengenai Bumi dan atmosfera. Ia ditadbir oleh pentadbiran NOAA (National Oceanic and Atmospheric Administration) di Amerika Syarikat untuk menyediakan imej langsung Bumi melalui radio, yang diterima oleh pengguna di lapangan. Walau bagaimanapun, akses kepada data imej satelit cuaca dalam masa nyata adalah terhad disebabkan oleh beberapa faktor seperti kos pembangunan yang mahal untuk sistem penerima, dan kekurangan kepakaran untuk menyahkod maklumat tersembunyi yang terkandung di dalamnya, dan masih dianggap sebagai isu utama yang dihadapi oleh peminat satelit. Oleh itu, tujuan projek ini termasuk mencipta prototaip stesen tanah yang mampu menyelesaikan tugas ini dan mendokumentasikan keseluruhan proses. RTL-SDR boleh menjadi salah satu alternatif yang lebih murah dan membantu peminat untuk meneroka RTL-SDR ini dengan lebih mendalam. Projek ini menggunakan komponen perisian dan perkakasan seperti WXtoImg, SDRsharp, Antena dan RTL-SDR untuk menerima data daripada satelit. RTL-SDR yang dipilih untuk digunakan dalam sistem ini ialah RTL-SDR 2832U. Perisian yang digunakan dalam projek ini ialah WXtoImg untuk menjana imej dan SDRsharp sebagai penyepaduan dengan RTL-SDR untuk memproses data daripada antena. Dalam projek ini, hasilnya menunjukkan imej bumi yang dipaparkan oleh komputer riba. Kesimpulannya, projek ini telah berjaya dibangunkan sebagai sistem maklumat cuaca dan mampu menghasilkan imej cuaca menggunakan penerima data satelit NOAA.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

ACKNOWLEDGEMENTS

Assalammualaikum and Peace Be Upon You. First and foremost, I would like to take this opportunity to express my grateful to Allah S.W.T because gave me a good health to finish up my final year project. I also would like to express my gratitude to my supervisor, DR. NOR AZLAN BIN MOHD ARIS for their precious guidance, words of wisdom and patient throughout this project.

I am also indebted to Universiti Teknikal Malaysia Melaka (UTeM) for both of my parent for the financial support, which enables me to accomplish the project. Not forgetting my fellow colleague, BEET Cohort 9 S2/1 for the willingness of sharing his thoughts and ideas regarding the project.

My highest appreciation goes to my parents and family members for their love and prayer during the period of my study. An honourable mention also goes to DR. NOR AZLAN BIN MOHD ARIS for all the motivation and understanding.

Finally, I would like to thank all the staffs at the FTKEE, fellow colleagues and classmates, the Faculty members, as well as other individuals who are not listed here for being co-operative and helpful.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

TABLE OF CONTENTS

	PAGE
DECLARATION	
APPROVAL	
DEDICATIONS	
ABSTRACT	**i**
ABSTRAK	**ii**
ACKNOWLEDGEMENTS	**iii**
TABLE OF CONTENTS	**iv**
LIST OF TABLES	**vi**
LIST OF FIGURES	**vii**
LIST OF ABBREVIATIONS	**ix**
LIST OF APPENDICES	**x**
CHAPTER 1 INTRODUCTION	**1**
1.1 Background	1
1.2 Problem Statement	2
1.3 Project Objective	2
1.4 Scope of Project	2
CHAPTER 2 LITERATURE REVIEW	**3**
2.1 Introduction	3
2.2 History of the United States polar weather satellites	4
2.2.1 First generation: TIROS Series (1960 - 1966)	4
2.2.2 Second generation: TOS series (1966 – 1969)	5
2.2.3 Third Generation: ITOS Series (1970 – 1976)	6
2.2.4 Fourth Generation: ATN Series (1978 – 1994)	6
2.2.5 Fifth Generation: NOAA-POES Series (1998 - 2009)	7
2.3 Future of weather satellites	9
2.3.1 JPSS-1 NOAA-20 (2017)	9
2.3.2 JPSS-2 (2022)	10
2.4 Theorical background NOAA satellites	10
2.5 Hardware	12
2.5.1 Antenna	12
2.5.1.1 Types of antennas for receiving NOAA satellite images	12
a . V-Dipole	12
b . Crossed Dipole or Turnstile	13
c . Quadrifilar helix antenna or QFH (Quadrifilar Helix)	15

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2.5.1.2 Antenna Design Procedure 15
2.5.2 RTL-SDR 17
2.5.3 Raspberry Pi 18
2.6 Software 18
2.6.1 Signal processing software 19
2.7 APT Signal 20
2.8 Comparison 21
2.9 Summary 25

CHAPTER 3 METHODOLOGY 26
3.1 Introduction 26
3.2 Study Design 26
3.3 Elaboration of process flow 29
3.4 Hardware specification 29
3.4.1 Bill of Material 29
3.4.2 RTL-SDR 2832U 30
3.4.3 Antenna 30
3.5 Software Specification 31
3.5.1 WxtoImg 31
3.5.2 SDR Sharp (AIRSpy) 32
3.6 Block Diagram of the project 33
3.7 Summary 34

CHAPTER 4 RESULTS AND DISCUSSIONS 35
4.1 Introduction 35
4.2 Software Development 35
4.3 Interface of the System 37
4.4 Results and Analysis 38
4.5 Testing with Low Noise Amplifier 44
4.6 Discussion 46
4.7 Summary 46

CHAPTER 5 CONCLUSION AND RECOMMENDATIONS 47
5.1 Conclusion 47
5.2 Recommendation for Future Works 47
5.3 Project Potential 48

REFERENCES 49

APPENDICES 51

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

LIST OF TABLES

TABLE	TITLE	PAGE
Table 2.1: NOAA satellite status description extracted from [3]		10
Table 2.2: Feature comparison between NOAA and IDEAM extracted from [3]		21
Table 2.3: Frequencies of NOAA Satellites extracted from [9]		21
Table 2.4: Comparison of Previous Research Papers		22
Table 3.1: Bill of Material (B.O.M)		29
Table 4.1: Results from V-Dipole antenna		38

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

LIST OF FIGURES

FIGURE	TITLE	PAGE
Figure 2.1: First image of the earth obtained from the TIROS-1 satellite extracted from [2]		4
Figure 2.2: Illustration of the TIROS-1 satellite and its components extracted from [2]5		
Figure 2.3: Illustration of two sun-synchronous polar orbiting satellites working together extracted from [2]		5
Figure 2.4: Illustration of NOAA-1, the big change in the design of the satellite extracted from [2]		6
Figure 2.5 Visible and electromagnetic spectra and detail of the AVHRR/1 channels extracted from [2]		7
Figure 2.6: Corrupted NOAA-15 APT images received by a hobbyist during an AVHRR engine trouble episode extracted from [2]		8
Figure 2.7: Illustration of a fourth generation satellite extracted from [2]		8
Figure 2.8: Illustration of NOAA-20 with details of its instruments extracted from [2]9		
Figure 2.9: Instruments and components of the POES satellites extracted from [3]		11
Figure 2.10: V-dipole antenna extracted from [2]		13
Figure 2.11: Components of a CP signal extracted from [2]		14
Figure 2.12: Turnstile antenna with a reflector extracted from [4]		14
Figure 2.13: QFH antenna extracted from [2]		15
Figure 2.14: Dimensions for the outer loop of QFH Antenna extracted from [5]		16
Figure 2.15: Dimensions for the inner loop of QFH Antenna extracted from [5]		16
Figure 2.16: Online Calculator Inputs extracted from [5]		16
Figure 2.17: RTL-SDR module extracted from [6]		17
Figure 2.18: Different ways of obtaining NOAA images extracted from [2]		19
Figure 3.1: Flowchart of project		27

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Figure 3.2: Flowchart of the system 28

Figure 3.3: RTL-SDR 2832U 30

Figure 3.4: QFH Antenna and V-Dipole Antenna 30

Figure 3.5: Software User Interface for WxtoImg 31

Figure 3.6: User Interface for SDR Sharp 32

Figure 3.7: Block Diagram Weather Information System using NOAA Satellite Data Retriever system with RTL-SDR 33

Figure 4.1: SDRsharp users' guideline 35

Figure 4.2: Main screen of the Gpredict software 36

Figure 4.3: Radio Control of NOAA 37

Figure 4.4: WXtoImg User Interface 37

Figure 4.5: WxtoImg Application 38

Figure 4.6: the MCIR Enhancement applied to the raw image. 40

Figure 4.7: Thermal Enhancement along with the heatmap scale 40

Figure 4.8: Satellite NOAA-19 heading northbound at Cheras, Kuala Lumpur 41

Figure 4.9: Rainy day affecting the antenna signal reception. 41

Figure 4.10: Clear day affecting the antenna signal reception 42

Figure 4.11: Simple portable ground station at Cheras, Kuala Lumpur 42

Figure 4.12: Simple portable station at Ayer Keroh, Malacca 43

Figure 4.13: Simple portable station at Fakuliti Kejuruteraan Mekanikal (FKM), UTeM 43

Figure 4.14: Simple portable at Taman Tasik Utama (TTU), Ayer Keroh 44

Figure 4.15: Low Noise Amplifier 44

Figure 4.16: Bandwidth from Low Noise Amplifier (LNA) 45

Figure 4.17: Block diagram for Low Noise Amplifier (LNA) 45

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

LIST OF ABBREVIATIONS

$RTL - SDR$	-	Realtek Software defined radio
$NOAA$	-	National Oceanic and Atmospheric Administration
$GOES$	-	Geostationary Operational Environmental Satellite
$POES$	-	Polar Operational Environmental Satellites
$QFH\ antenna$	-	Quadrifilar helicoidal antenna
APT	-	Automatic Picture Transmission
$HRPT$	-	High Resolution Picture Transmission
$AVHRR$	-	Advanced Very High-Resolution Radiometer
SNR	-	Singal to Noise Ratio

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
Appendices 1.1	Gantt Chart for PSM 1	59
Appendices 5.2	Gantt Chart for PSM 2	60

UTeM
اونيۆرسيتي تيكنيكل مليسيا ملاك
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

CHAPTER 1

INTRODUCTION

1.1 Background

The National Oceanic and Atmospheric Administration’s (NOAA) is an American scientific agency which has launched 19 satellites that focuses on forecasting changes in climate, coast, weathers and oceans. At present NOAA-19, NOAA-18 and NOAA-15 there are geosynchronous satellites active with Automatic Picture Transmission (APT) feature, orbiting at an altitude around 830km. These satellites are equipped with a variety of instruments, including the AVHRR (Advanced Very High-Resolution Radiometer), which detects the reflection of electromagnetic waves by clouds, surface waters, and objects on the earth's surface. Then, there are two popular services such as APT (Automatic Picture Transmission) data and HRPT (High Resolution Picture Transmission). So that to receive NOAA APT satellite data, the system is needed in the form of an antenna that matches the working frequency of the VHF (Very High Frequency) band at a frequency of 137 Mhz.
Furthermore, the live weather images are broadcasted by the APT signals. The objective is to produce a low-cost base station using a Software Defined Radio (SDR) and a suitable antenna (Quadrifilar Helix Antenna, V Dipole Antenna) to receive NOAA and Meteor-M2 satellite signals and decode them using several open-source software's (SDR#, WxToImg, Orbitron, LRPT Decoder) to obtain real-time images when the satellite is overhead. [1]

1.2 Problem Statement

Access to weather satellite image data in real-time is limited due to several factors such expensive development cost for a retriever system, and lack of expertise to decode the hidden information contained in it and are still considered a major issue faced by satellite enthusiasts. Therefore, RTL-SDR could be one of the alternatives that is cheaper and assist enthusiasts explore this RTL-SDR deeper. Then, to generate weather images from satellites by using hardware is expensive and mostly by using the agencies such as NOAA, Pustekdata LAPAN and MET Malaysia. By using this hardware as little as possible it can help to reduce price to run this project.

However, not many areas in Malaysia can achieve high-speed internet such as fiber optic especially those in rural areas. With the limitation internet, an area it’s hard to get information weather. With this RTL-SDR it can get information weather directly from satellite without using the internet.

1.3 Project Objective

1. To develop a low-cost receiver system to receive NOAA satellite data using RTL SDR.
2. To analyze the performance of the receiver system.
3. To process the received satellite data into image of atmospheric weather.

UTeM
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

1.4 Scope of Project

The scope of this project is to develop an acquisition system of NOAA satellite data by using an RTL-SDR to process the satellite raw data generated into the image. The image data can be monitored by the user’s and examine that image via the application known as WxtoImg in real-time imagery. This system consists of an RTL-SDR as the process of the system and an antenna as a medium of receiver of the information.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The main objective of this project is the implementation of a ground station that is capable of autonomously receiving images from operational NOAA satellites. These satellites capture images of the Earth and the atmosphere in both visible and infrared spectra as they orbit. The images are transmitted to the ground at a frequency of 137 MHz on FM, using a simple protocol called APT. They can be received by receivers that cover that band and decoded using the appropriate software on a computer.

Lately, RTL-SDR receivers have become popular that connect to the USB port of a computer and that allow receiving a wide variety of signals in a very economical way. These are widely used, among others, for the reception of NOAA satellite signals, since the only equipment required is: a computer, an appropriate antenna for the frequency at which you want to receive, and one of these receivers. It was the experimentation of the above, which has inspired the realization of this project, seeking to delve deeper into this subject, and applying the knowledge learned both within the degree, and by own hobby. To take what was experienced further, it was decided that this entire process of receiving images, which required the intervention of a person to control the different software, would be automated; and that the laptop (with the RTL-SDR USB receiver connected) that controlled it, would become a Raspberry PI, with the aim of putting everything in a small transportable box. The only thing that would be left out of the box would be the antenna, from which a more elaborate model would be built, suitable for the NOAA signal [2].

2.2 History of the United States polar weather satellites

2.2.1 First generation: TIROS Series (1960 - 1966)

On April 1, 1960, the first meteorological satellite was launched, successfully capturing photographs of the Earth from space (Figure 2.1) and transmitting them to Earth stations through radio.

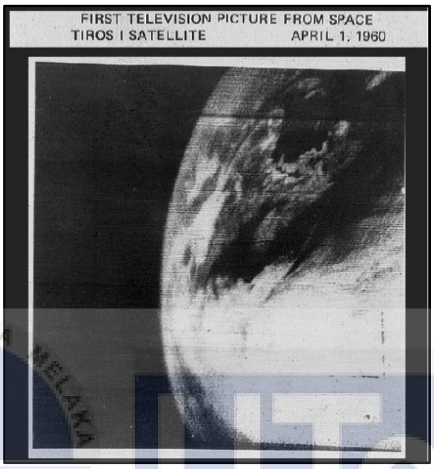


Figure 2.1: First image of the earth obtained from the TIROS-1 satellite extracted from [2]

It should be noted that being a spin stabilized satellite (at 12 RPM), most of the time, the satellite and the cameras were not pointing towards the Earth (Figure 2.2). The images and telemetry data were transmitted to Earth via radio, with a 235 MHz FM downlink, using a circularly polarized cross dipole antenna or Turnstile located at the bottom of the satellite (Figure 2.2). It could also receive commands sent from Earth via a monopole antenna on top. Regarding the ground stations responsible for receiving this data, they were distributed throughout the United States. The satellite also had radio beacons, which allowed its location and tracking, thanks to receiving stations spread throughout the American continent. [2]

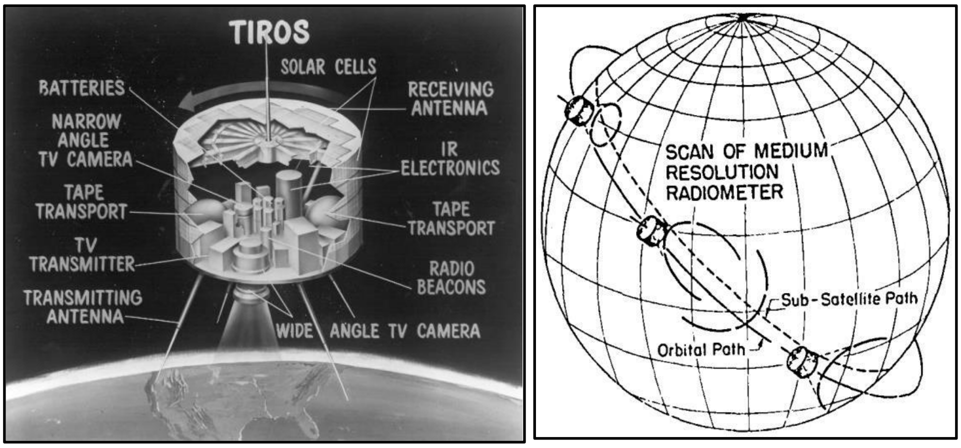


Figure 2.2: Illustration of the TIROS-1 satellite and its components extracted from [2]

2.2.2 Second generation: TOS series (1966 – 1969)

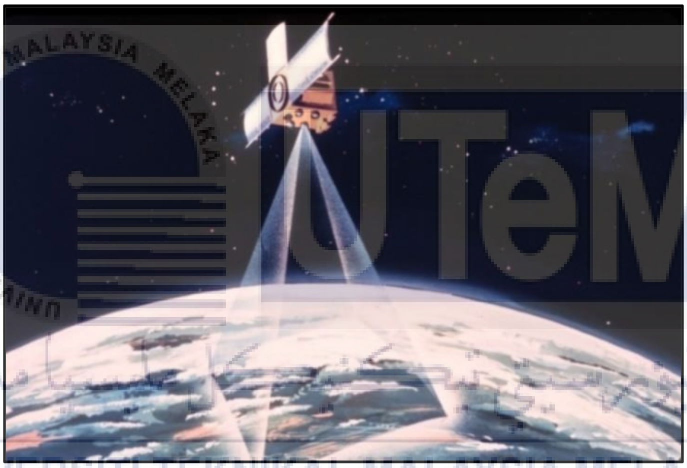
The first satellites of the TOS (TIROS Operational System) series, finally called ESSA-1 and ESSA-2 (Enviromental Science Services Administration) satellites, were launched in February 1966, being the first to work together in the same polar sun orbit. -synchronous (Figure 2.3) at 1400km altitude. They had a mass of 304 kg and a design very similar to that of the previous TIROS series. One of the satellites was obtaining daytime images while the other was capturing night-time images. [2]

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Figure 2.3: Illustration of two sun-synchronous polar orbiting satellites working together extracted from [2]

2.2.3 Third Generation: ITOS Series (1970 – 1976)

The ITOS (Improved Shots Operational System) series of satellites, finally designated NOAA (due to the founding of the administration on October 3, 1970), began with NOAA-1, launched on December 11, 1970, with a mass of 307kg. In this satellite, in addition to the new designation, important changes were induced. The most visible change is that the TIROS-1's signature 18-sided prism-shaped chassis was phased out in favour of a nearly cubic chassis (1m by 1m by 1.2m) (Figure 2.4). Satellite stabilization was no longer by spin, instead using 3-axis stabilization, based on moment wheels coupled to electric motors, which allowed for better manoeuvrability and precise control of the satellite's attitude. This translated into the ability to get better images for longer.



UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Figure 2.4: Illustration of NOAA-1, the big change in the design of the satellite extracted from [2]

2.2.4 Fourth Generation: ATN Series (1978 – 1994)

In the ATN (Advanced TIROS-N) series we find the TIROS-N, launched on October 13, 1978, with a mass of 589kg. It began to equip the AVHRR (Advanced Very High-Resolution Radiometer) sensor, which, as its name suggests, is an evolution of the VHRR. The sensor was composed of four radiometers (4 channels) (Figure 2.5):

- Channel 1: Visible light, from 0.55 to 0.9 µm. Used for daytime terrain and cloud mapping.
- Channel 2: Near Infrared, from 0.725 to 1.1 µm. Mapping of surface water and vegetation.
- Channel 3: Infrared atmospheric window, from 3.55 to 3.93 µm. SST sea surface temperature and fire detection.
- Channel 4: Infrared atmospheric window, from 10.5 to 11.5 µm. Sea surface temperature and cloud mapping at night.

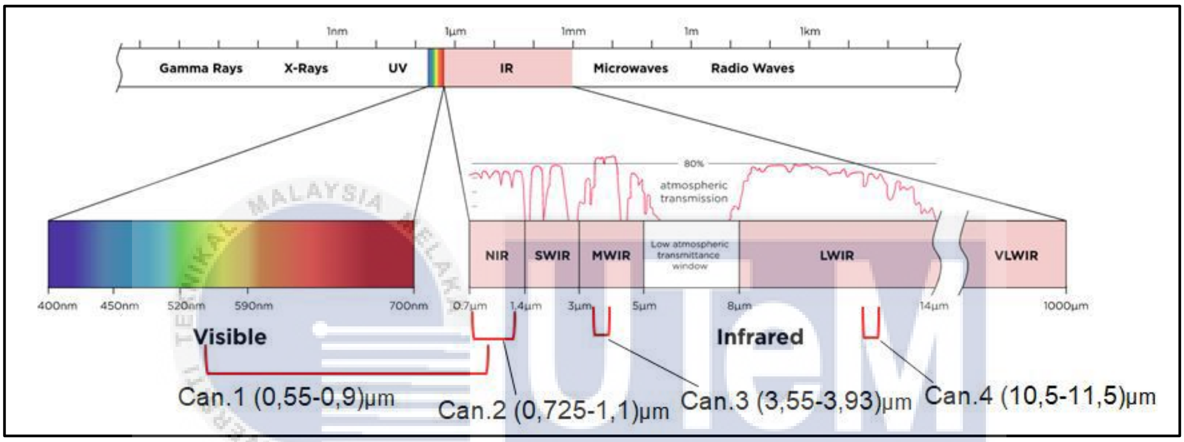


Figure 2.5 Visible and electromagnetic spectra and detail of the AVHRR/1 channels extracted from [2]

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2.2.5 Fifth Generation: NOAA-POES Series (1998 - 2009)

The first of the fifth generation, NOAA-15, was launched on May 13, 1998 and is still in service. It has a mass of 1457kg and is in a sun-synchronous orbit at an altitude of 870km. It equips the AVHRR/3 sensor, which includes an extra infrared channel (compared to the AVHRR/2) called 3A from 1.58 to 1.64µm (the old channel 3 is now called 3B), which means that it now has 6 channels.

NOAA-15 has far exceeded the estimated time of its mission (between 2 to 5 years for this class of satellites), having already been in service for 23 years. However, some of the sensors and/or systems have lost capabilities or are out of service. To be highlighted, the intermittent failure in the motor that rotates the AHRR scanning mirror: since 2002 there have been some episodes of current peaks in the motor that cause corrupted images (Figure 2.6).

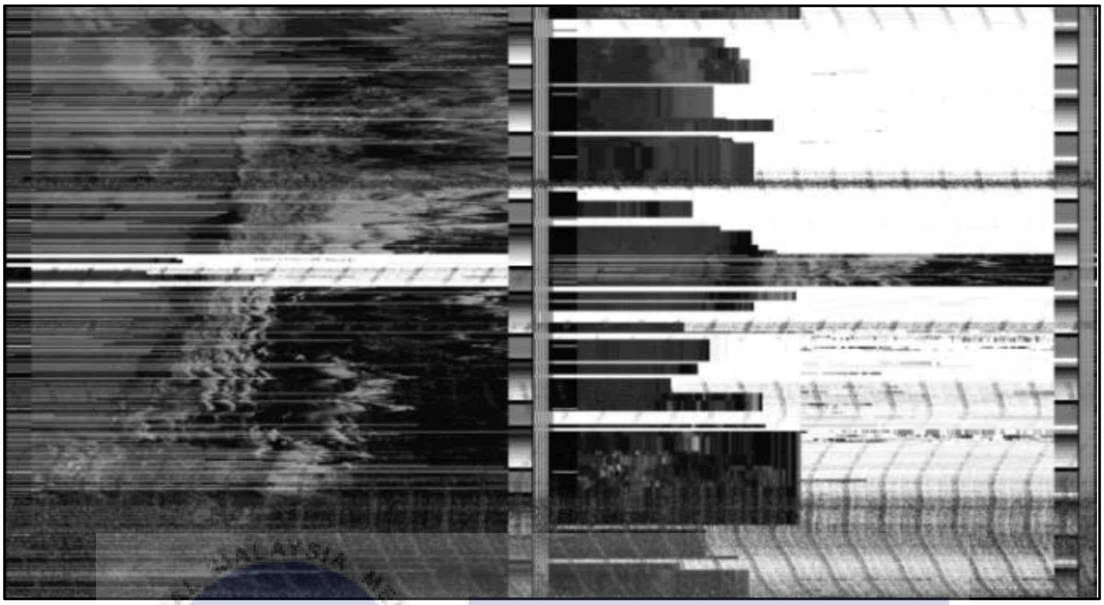


Figure 2.6: Corrupted NOAA-15 APT images received by a hobbyist during an AVHRR engine trouble episode extracted from [2]

The NOAA-18 satellite, launched on May 20, 2005, with instrumentation and characteristics (weight, orbit, etc.) similar to those of NOAA-15. It is still in service today. The NOAA-19 satellite, launched on February 6, 2009, with similar instrumentation and characteristics (weight, orbit, etc.) as its predecessors in the series. It is the last satellite of the fifth generation and continues in service today. [2]

Figure 2.7: Illustration of a fourth generation satellite extracted from [2]