ECOSWEEP: UNIVERSAL MULTI-TERRAIN CLEANING ROBOT

A Project Report

Submitted in partial fulfilment of the
requirements for the award of the Degree of

BACHELOR OF SCIENCE (INFORMATION TECHNOLOGY)

By

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VSIT | Vidyalankar School of Information Technology
RE-ACCREDITED : GRADE 'A' BY NAAC

DEPARTMENT OF INFORMATION TECHNOLOGY AND DATA SCIENCE

VIDYALANKAR SCHOOL OF INFORMATION TECHNOLOGY

(Affiliated to University of Mumbai)

MUMBAI, 400 037

MAHARASHTRA

2025 - 2026

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CERTIFICATE

This is to certify that the project entitled, **"Ecosweep: Universal Mult-terrain Cleaning Robot"**, is bonafied work of **FARHAN FAIZAN SAYED** bearing Seat No: 23302A0047 submitted in partial fulfilment of the requirements for the award of degree of BACHELOR OF SCIENCE in INFORMATION TECHNOLOGY from University of Mumbai.

Internal Guide **Coordinator**

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1. **COMPANY CERTIFICATE (for LIVE Project)**
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ABSTRACT

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DECLARATION

I hereby declare that the project entitled, "**ECOSWEEP**" done at Vidyalankar School of Information Technology, has not been in any case duplicated to submit to any other universities for the award of any degree. To the best of my knowledge other than me, no one has submitted to any other university.

The project is done in partial fulfillment of the requirements for the award of degree of **BACHELOR OF SCIENCE (INFORMATION TECHNOLOGY)** to be submitted as final semester project as part of our curriculum.

Name and Signature of the Student

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Chapter 1 Introduction

1.1 Background

In the modern era, rapid urbanization, rising population, and increasing lifestyle demands have created a significant need for sustainable and efficient cleaning solutions. Traditional cleaning methods are labor-intensive, time-consuming, and often ineffective in large-scale or complex environments. Moreover, manual cleaning in hazardous or hard-to-reach areas exposes workers to potential health risks and physical strain. To address these issues, the integration of robotics and automation in cleaning has emerged as a promising technological advancement.

Robotics, combined with Artificial Intelligence (AI) and sensor-driven navigation, is revolutionizing various industries, including healthcare, manufacturing, and household services. One of the most practical applications of robotics in everyday life is **automated cleaning systems**, which can operate in diverse terrains and adapt to different environments. Existing robotic cleaning solutions, such as commercial vacuum robots, are often limited in functionality, designed for smooth indoor floors, and lack flexibility in handling outdoor or uneven surfaces.

The **EcoSweep Project** has been conceptualized as a universal, multi-terrain cleaning robot capable of addressing these challenges. Unlike conventional systems, EcoSweep is designed to be **versatile, intelligent, and scalable**. It aims to bridge the gap between household-level cleaning robots and industrial-scale cleaning machinery by providing a cost-effective, adaptable, and environment-friendly solution.

The backbone of EcoSweep lies in its hybrid architecture combining **Arduino Mega 2560** for low-level hardware control, **Raspberry Pi 4** for high-level decision-making and communication, and a suite of sensors (ultrasonic, IR, GPS, compass, IMU) for navigation and obstacle detection. Additionally, the robot employs a **custom PCB design** for seamless integration of components and a modular power management system that ensures stable operation.

By addressing the shortcomings of current robotic cleaning solutions and emphasizing multi-terrain adaptability, EcoSweep sets the foundation for a sustainable and technologically advanced cleaning ecosystem.

1.2 Objectives

The objectives of the EcoSweep project are outlined as follows:

1. **Design and Development:**
   To design and build a functional robotic cleaning system that integrates mechanical, electronic, and software components for efficient operation across different terrains.

2. **Versatility in Cleaning:**
   To ensure that the robot can handle **indoor, outdoor, smooth, and uneven surfaces**, making it suitable for domestic, institutional, and industrial applications.
3. **Efficient Navigation and Control:**
   To implement a navigation system that uses a combination of sensors (ultrasonic, infrared, GPS, IMU, compass) for real-time obstacle avoidance and path correction.
4. **Modular Communication System:**
   To establish a reliable communication link between the **Flutter mobile app → Raspberry Pi → Arduino Mega**, enabling real-time manual and semi-autonomous control.
5. **Energy Efficiency and Safety:**
   To design a **dual power supply system** using Li-Po and Li-ion batteries with proper voltage regulation, ensuring safety, durability, and uninterrupted operation.
6. **Future Expandability:**
   To develop a platform that can be upgraded with **AI-based vision, autonomous decision-making, and advanced cleaning mechanisms** in future phases.

1.3 Purpose, Scope, Applicability (Feasibility Study)

Purpose

The purpose of EcoSweep is to create a **universal cleaning robot** that simplifies the process of maintaining hygiene in both domestic and industrial environments. It addresses limitations of existing robotic cleaners by incorporating **multi-terrain adaptability, robust hardware, and modular expandability**. The project not only provides a cost-effective alternative to current solutions but also encourages sustainable practices through efficient energy use and reduced dependency on manual labor.

Scope

The scope of EcoSweep extends across multiple domains:

- **Domestic Use:** Cleaning residential floors, tiles, and semi-rough surfaces.
- **Institutional Applications:** Maintaining cleanliness in schools, offices, hospitals, and public spaces.
- **Industrial Environments:** Handling dust and debris in warehouses, workshops, and semi-rough outdoor areas.
- **Future Research Platform:** Serving as a base for **AI, computer vision, and IoT integration**, enabling researchers to expand functionalities.

Feasibility Study

The feasibility of EcoSweep is evaluated across three aspects:

1. **Technical Feasibility:**
   a. Hardware components such as **Arduino Mega, Raspberry Pi, PCA9685, BTS7960 drivers, and multiple sensors** are readily available and cost-effective.

   b. Existing communication technologies (Classic Bluetooth, USB serial) provide a reliable framework for real-time control.
   c. Modular PCB design ensures scalability and reduces wiring complexities.
2. **Economic Feasibility:**
   a. Compared to high-cost industrial cleaning machines, EcoSweep offers a **low-cost prototype solution** using open-source platforms and affordable hardware.
   b. Long-term maintenance and upgrades can be performed with minimal expenses due to modular architecture.
3. **Operational Feasibility:**
   a. The robot can be operated via a **mobile app interface**, making it user-friendly for non-technical users.
   b. Manual and semi-automatic modes allow flexibility in deployment across various scenarios.
   c. The phased development approach ensures gradual improvement and easier adoption.

Chapter 2 Survey of Technologies

2.1 Introduction

The advancement of robotics and automation has significantly transformed cleaning technologies in domestic, institutional, and industrial environments. Numerous robotic cleaning systems exist in the market today, ranging from small household vacuum robots to large-scale industrial sweepers. However, these systems often suffer from limitations such as **restricted terrain adaptability, high cost, dependency on smooth surfaces, and limited scalability**.

In this chapter, we review and analyze **existing robotic cleaning technologies, navigation and control mechanisms, power management strategies, and communication systems**. This survey establishes the foundation for developing **EcoSweep**, a universal cleaning robot that overcomes the shortcomings of current solutions.

2.2 Existing Robotic Cleaning Technologies

1. **Household Cleaning Robots (e.g., Roomba, Mi Robot Vacuum):**
    a. *Features:* Compact size, automated vacuuming, obstacle detection using IR/ultrasonic sensors.
    b. *Limitations:* Restricted to smooth indoor floors, limited battery life, lacks multi-terrain adaptability.
    c. *Relevance to EcoSweep:* Provides a baseline for domestic cleaning functionality, but EcoSweep aims to expand beyond indoor use.
2. **Industrial Floor Cleaning Machines (e.g., Tennant, Nilfisk):**
    a. *Features:* Large-scale cleaning with powerful suction/sweeping mechanisms, high durability.
    b. *Limitations:* Very expensive, requires skilled operators, unsuitable for small-scale/domestic environments.
    c. *Relevance to EcoSweep:* Highlights the gap between high-end industrial machines and low-end domestic robots.
3. **Semi-Autonomous Cleaning Robots (Research Prototypes):**
    a. *Features:* Integration of AI, computer vision, and advanced sensors for navigation.
    b. *Limitations:* Still under research, high computational demand, costly hardware.
    c. *Relevance to EcoSweep:* Provides direction for future expansion into AI and vision-based cleaning.

2.3 Technologies in Navigation and Control

1. **Sensor-Based Navigation:**
    a. Uses ultrasonic sensors, IR sensors, and bump sensors for obstacle detection.

    b. Simple, cost-effective, but less accurate on complex terrains.
    c. EcoSweep integrates **ultrasonic + IR + IMU + GPS + compass** for hybrid navigation.
2. **Camera/AI-Based Navigation:**
    a. Uses cameras and AI models for object recognition and path planning.
    b. Highly accurate but computationally expensive.
    c. Planned for **Phase 3** of EcoSweep, once manual and semi-auto modes are validated.
3. **Microcontroller vs. Single-Board Computer Control:**
    a. *Microcontrollers (e.g., Arduino Mega):* Excellent for hardware-level control, motor drivers, and real-time responses.
    b. *Single-Board Computers (e.g., Raspberry Pi 4):* Suitable for decision-making, Bluetooth communication, and high-level processing.
    c. EcoSweep combines both, ensuring reliability and expandability.

2.4 Power Management in Robotic Systems

- **Li-Po Batteries:** Lightweight, high discharge rate, ideal for motors.
- **Li-Ion Batteries:** Stable, safe, ideal for sensors and controllers.
- **Hybrid Power Systems:** Many existing robots rely on a single battery pack, limiting efficiency.
- **EcoSweep Advantage:** Uses **Li-Po for motors** and **Li-Ion with buck converters for electronics**, ensuring balanced performance and longer run time.

2.5 Communication Technologies

1. **Wi-Fi Based Control:**
    a. Provides high data rate, good for video streaming.
    b. Limitation: Limited range, high power consumption.
2. **Bluetooth-Based Control:**
    a. Simple, cost-effective, widely supported by smartphones.
    b. Ideal for short-range manual/semi-auto control.
    c. EcoSweep uses **Classic Bluetooth → Raspberry Pi → USB Serial → Arduino Mega**.
3. **IoT/Cloud-Based Control:**
    a. Used in advanced industrial systems for remote monitoring.
    b. Requires strong internet connectivity.
    c. Future scope for EcoSweep in large-scale deployments.

2.6 Comparison of Technologies

Technology	Existing Systems	Limitations	EcoSweep Improvement
Cleaning Robots	Roomba, Mi Robot	Indoor only, limited terrain	Multi-terrain adaptability
Industrial Machines	Tennant, Nilfisk	Very expensive, bulky	Cost-effective, scalable
Navigation	Sensor/AI-based	Either simple or expensive	Hybrid sensor + expandable to AI
Power	Single-battery systems	Limited efficiency	Hybrid dual power supply
Communication	Wi-Fi/Bluetooth/IoT	Range/cost limitations	Reliable Bluetooth + modular design

2.7 Summary

The survey highlights that while numerous cleaning robots exist, **none provide a cost-effective, multi-terrain, and modular solution** suitable for both domestic and industrial contexts. Most systems are either too simple (limited to indoor domestic cleaning) or too costly (industrial-grade machines). EcoSweep is positioned as an **intermediate yet scalable platform**, combining the **affordability and accessibility of domestic robots** with the **robustness and expandability of industrial systems**.

Chapter 3 Requirements and Analysis

3.1 Problem Definition

Maintaining cleanliness in modern environments—whether homes, institutions, or industrial spaces—is both essential and challenging. Traditional cleaning methods are labour-intensive, time-consuming, and often inefficient in handling large or complex areas. While robotic cleaning technologies such as vacuum robots have been introduced, they are predominantly designed for smooth indoor floors and lack adaptability for uneven terrains, outdoor surfaces, or multi-purpose cleaning. On the other end of the spectrum, large industrial cleaning machines are available, but they are prohibitively expensive, bulky, and require skilled operators, making them unsuitable for small to medium-scale use.

The absence of a **cost-effective, multi-terrain, and modular cleaning solution** creates a significant gap between **domestic robotic cleaners** and **industrial cleaning systems**. Current solutions also face limitations in energy efficiency, scalability, and communication reliability. Moreover, most available cleaning robots do not offer expandability for integration with advanced technologies such as Artificial Intelligence, computer vision, or IoT-based monitoring, which limits their long-term applicability.

The **EcoSweep Project** addresses these issues by proposing a **universal cleaning robot** that combines the affordability and accessibility of household robotic systems with the robustness and adaptability of industrial systems. The design integrates **Arduino Mega 2560** for low-level hardware control and **Raspberry Pi 4** for communication and high-level processing, supported by sensors (ultrasonic, IR, GPS, IMU, compass) for navigation and obstacle avoidance. A dual power supply system ensures stability and extended runtime.

The problem at hand, therefore, is to design and implement a **universal robotic cleaning system** that is:

- Adaptable to multiple terrains (indoor, outdoor, smooth, and uneven surfaces).
- Cost-effective and suitable for both small-scale and medium-scale cleaning needs.
- Energy-efficient and equipped with robust communication between hardware and mobile applications.
- Expandable for future integration of AI, computer vision, and IoT technologies.

3.2 Requirement Specification

To achieve the stated objectives and solve the defined problem, the EcoSweep system requires a well-structured set of **functional** and **non-functional requirements**.

3.2.1 Functional Requirements

These define the core operations and features the system must support:

1. **Movement and Navigation:**
    a. The robot must be able to move in forward, backward, left, and right directions with smooth speed control.
    b. The navigation should be assisted by ultrasonic and IR sensors for obstacle detection.
    c. GPS and compass modules should provide basic location and direction tracking.
2. **Cleaning Mechanism:**
    a. The system should support a cleaning mechanism capable of sweeping or collecting dust and debris.
    b. A robotic arm with servo motors should assist in versatile cleaning tasks.
3. **User Control via Mobile Application:**
    a. A **Flutter-based mobile app** should allow manual control of the robot.
    b. The app should communicate with the Raspberry Pi over **Classic Bluetooth**, which then forwards commands to Arduino Mega via USB serial.
    c. Commands for both **tire motors** and **robotic arm servos** must be supported.
4. **Power Management:**
    a. A dual battery system must be implemented:
        i. **Li-Po battery** for high-power DC motors.
        ii. **Li-ion battery** with buck converters for sensors and controllers.
    b. The system should monitor and regulate power distribution to avoid overloading.
5. **Modes of Operation:**
    a. **Manual Mode:** User-controlled via mobile app.
    b. **Semi-Automatic Mode:** Sensor-assisted navigation for basic obstacle avoidance.
    c. **Future Autonomous Mode:** AI-enhanced navigation and vision-based decision-making.

3.2.2 Non-Functional Requirements

These specify the quality, reliability, and performance expectations of the system:

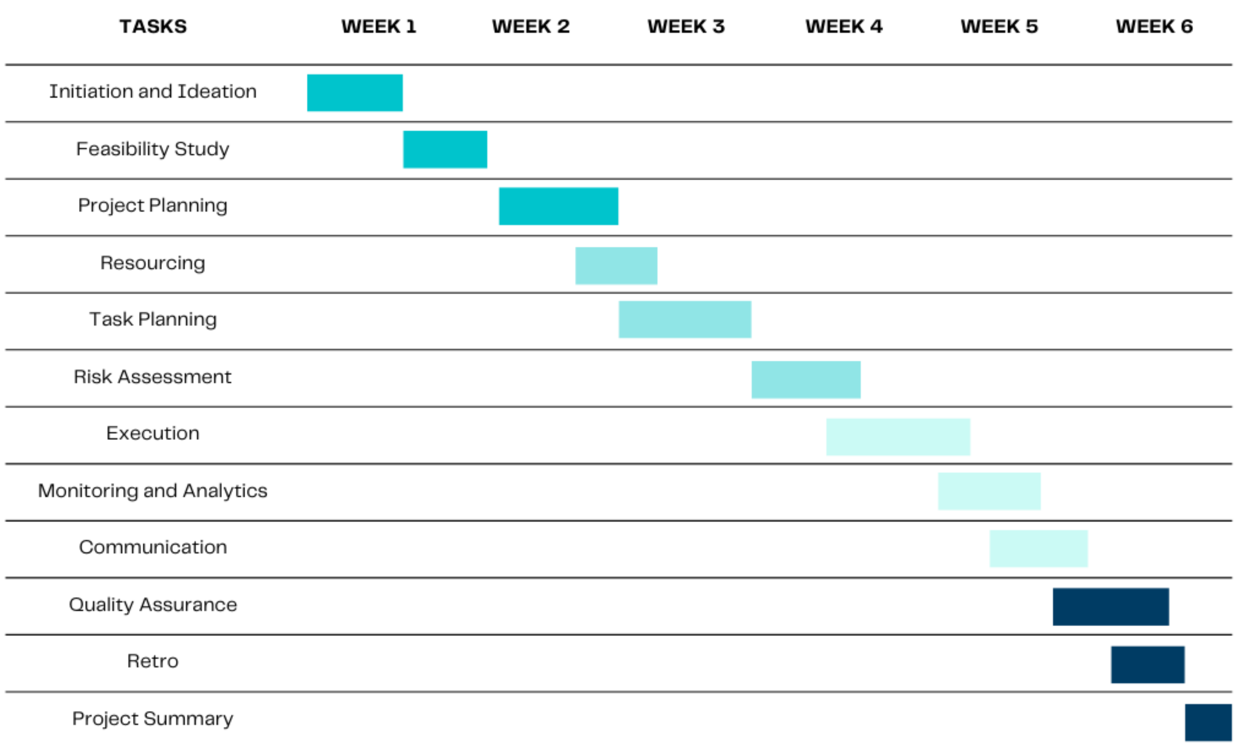
1. **Reliability:**
    a. The system should function continuously for a minimum of 1 hour on a single charge.
    b. Communication between the app, Raspberry Pi, and Arduino Mega must remain stable during operation.
2. **Scalability:**
    a. The architecture should allow integration of additional sensors, modules, or AI features without major redesign.
3. **Safety:**
    a. Power circuits must include overcurrent protection to safeguard components.
    b. The cleaning mechanism must operate without posing harm to the user.
4. **Usability:**
    a. The mobile application must provide an intuitive interface, accessible to users with minimal technical expertise.
5. **Maintainability:**

    a. The modular design of both hardware and software should make it easy to repair, upgrade, or extend the system.

6. **Performance:**
    a. The robot must respond to user commands with minimal latency (<200 ms).
    b. Navigation accuracy should remain within acceptable tolerance limits (±10 cm for sensor-based detection).

3.3 Planning and Scheduling

Gantt Chart – Sem V



PERT Chart – Sem V

3.4 Software and Hardware Requirement

Software Component	Description and Purpose

Arduino IDE	Used to write, compile, and upload code to the Arduino Mega 2560. The Arduino IDE supports C/C++ programming and provides built-in libraries for easy integration of hardware components like sensors and motor drivers.
Python 3.x	Used on Raspberry Pi for Bluetooth server development, serial communication with Arduino Mega, and handling high-level control logic. Python provides simplicity and ease of use in communication and control scripts.
KiCad EDA	Used for designing the custom PCB layout. KiCad is an open-source software tool that provides schematic capture and PCB design functionality, allowing us to build a single-sided PCB for EcoSweep.
Flutter (Dart)	The mobile application for user control is developed using Flutter framework. Flutter provides a cross-platform mobile solution with a rich user interface and integration with Bluetooth libraries for real-time communication.
Bluetooth Libraries (Flutter Blue Plus)	Provides Bluetooth Classic functionality in the mobile app to scan, connect, and communicate with the Raspberry Pi over Bluetooth SPP (Serial Port Profile).
Operating System – Raspberry Pi OS (32-bit)	Lightweight and compatible with Raspberry Pi hardware. It supports Python, Bluetooth tools, and USB serial communication, providing a stable environment for the control software to run.
Git (Version Control)	For source code management and tracking development progress over time. Git ensures easy collaboration and versioning of project files.
PuTTY / minicom	Used for serial debugging and monitoring communication between Raspberry Pi and Arduino Mega during development and testing phases.

3.4.2 Hardware Requirement

Hardware Component	Description and Purpose
Arduino Mega 2560	Serves as the primary low-level microcontroller responsible for controlling tire motors, servo motors, sensors, and handling real-time hardware tasks.
Raspberry Pi 4 (4GB)	Acts as the high-level processor, managing Bluetooth communication with the mobile app and forwarding commands to Arduino Mega via USB serial.
PCA9685 Servo Driver Module	Provides PWM control signals to drive up to 16 servo motors for the robotic arm, allowing precise movement.
BTS7960 Motor Driver	High-power motor driver module to control 4 DC tire motors for movement across terrains. It handles high currents from the LiPo battery safely.
NEO-6M GPS Module	Provides basic location data to assist in navigation and future expansion for autonomous mode.
MPU6050 (Accelerometer + Gyroscope)	Helps detect orientation, tilt, and motion of the robot, used for stability and navigation assistance.
HMC5883L Magnetometer (Compass Module)	Provides directional heading data to help maintain correct robot orientation during movement.

Ultrasonic Sensors (HC-SR04)	Used for obstacle detection and measuring distance to nearby objects in real time. Three sensors are mounted at different angles for 360° sensing coverage.
Infrared (IR) Sensors	Supports line detection and edge detection functionality, useful in semi-autonomous navigation.
Li-Po Battery (7.4V or 11.1V)	Powers the high-current-consuming components such as DC motors for movement.
Li-Ion Battery Pack	Powers sensors, microcontrollers (Arduino, Raspberry Pi), and communication modules with a buck converter to maintain stable voltage.
Buck Converter (LM2596)	Reduces and regulates battery voltage to suitable levels (5V, 3.3V) required by electronics.
Bluetooth Module (Classic SPP)	Enables Bluetooth communication between the mobile app and Raspberry Pi. Classic Bluetooth provides stable and low-latency serial communication.
Custom Single-Sided PCB	Provides organized, compact, and reliable electrical connections between components, eliminating messy wires and improving robustness.
Chassis with DC Tires and Robotic Arm	The mechanical structure that holds all components and allows mobility and cleaning mechanism operations.
Power Switches and Connectors	Used for controlling power distribution and providing modularity in connections.

Chapter 4 System Design

4.1 Basic Modules

4.2 Data Design (Table Design)

4.2.1 Schema Design

4.2.2 Data Integrity and Constraints

4.3 Diagrams

4.3.1 E-R Diagram /Block Diagram

4.3.2 Class Diagram / Data Flow Diagram

4.3.3 Use Case Diagram

4.3.4 Sequence Diagram

4.3.5 Activity Diagram

4.3.6 Component Diagram

4.3.7 Menu Tree / Circuit Diagram

4.3.8 Event Table

4.3.9 User Interface Design

4.3.10 Security Issues

4.3.11 Test Cases Design

References

It is very important that the students acknowledge the work of others that they have used or adapted in their own work, or that provides the essential background or context to the project. The use of references is the standard way to do this. Please follow the given standard for the references for books, journals, and online material. The citation is mandatory in both the reports.

E.g:

Linhares, A., & Brum, P. (2007). Understanding our understanding of strategic scenarios: What role do chunks play? Cognitive Science, 31(6), 989-1007. https://doi.org/doi:10.1080/03640210701703725

Lipson, Charles (2011). Cite right : A quick guide to citation styles; MLA, APA, Chicago, the sciences, professions, and more (2nd ed.). Chicago [u.a.]: University of Chicago Press. p. 187. ISBN 9780226484648.

Elaine Ritchie, J Knite. (2001). Artificial Intelligence, Chapter 2 , p.p 23 - 44. Tata McGrawHill.

Bibliography

Website Used

Please mention the full URL and Date of Access of URL

Glossary

If you the students any acronyms, abbreviations, symbols, or uncommon terms in the project report then their meaning should be explained where they first occur. If they go on to use any of them extensively then it is helpful to list them in this section and define the meaning.

Appendices

These may be provided to include further details of results, mathematical derivations, certain illustrative parts of the program code (e.g., class interfaces), user documentation etc.

In particular, if there are technical details of the work done that might be useful to others who wish to build on this work, but that are not sufficiently important to the project as a whole to justify being discussed in the main body of the project, then they should be included as appendices.

Summary

Project development usually involves an engineering approach to the design and development of a software system that fulfils a practical need. Projects also often form an important focus for discussion at interviews with future employers as they provide a detailed example of what the students are capable of achieving.

Further Reading

1. Modern Systems Analysis and Design; Jeffrey A. Hoffer, Joey F. George, Joseph,S. Valacich; Pearson Education; Third Edition; 2002.

2. ISO/IEC 12207: Software Life Cycle Process

(http://www.software.org/quagmire/descriptions/iso-iec12207.asp).

Plagiarism Report

[Max allowed range is 10-15 %]