Chapter 1

Introduction

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1.0 Background:

The background of this research centers around shifting the usage of industrial robot from large enterprises to the small and medium size business. This thesis loosely refers an industrial robot as a robot manipulator that is used in automation per definition ISO-8373:2 (2021). Thus, any manipulators with more than three controllable joints used in an automation for production purposes are considered as and industrial robot. However, the stigma prevails; industrial robots are heavy, expensive, inflexible, high maintenance, and hazardous which require informed safety precautionaries. In practice, a heavy industrial robot is isolated into work cells making the operation of industrial robots rigid, inflexible, and require tremendous amount of time and resources should a new task or change is required in the workcell (Miseikis et al. 2017). This stigma and the reality of owning an industrial robot hinders the confidence of small and medium size business (SME) to adopt industrial robot technology. This thesis attempts to democratize robot technology and automation to the SMEs by introducing an inexpensive, flexible, and safe robotic technology.

To increase flexibility and decrease the cost of operating and maintaining an industrial robotic system for a large production in an SME setup, we propose an FAS characterized by the ability to react to unpredictable changes in its production floor. The main purpose of the FAS is to maintain and manage the uncertainty of the system so that the system will be safe to use at a low cost. Three aspects of an FAS for an industrial robot~~;~~ (1) visual feedback, (2) map model and state estimation model of the robot, and (3) path planning model of the robot. Figure 1.1 shows these considerations. The FAS uses visual feedback, such as visual camera, laser range finder, or a visual-depth camera, to model the workspace and to model the state of the robot.

what FAS stands for? Any abbreviation appears for the first time must have its expanded form.

The second aspect of an FAS is the state estimation model and the map

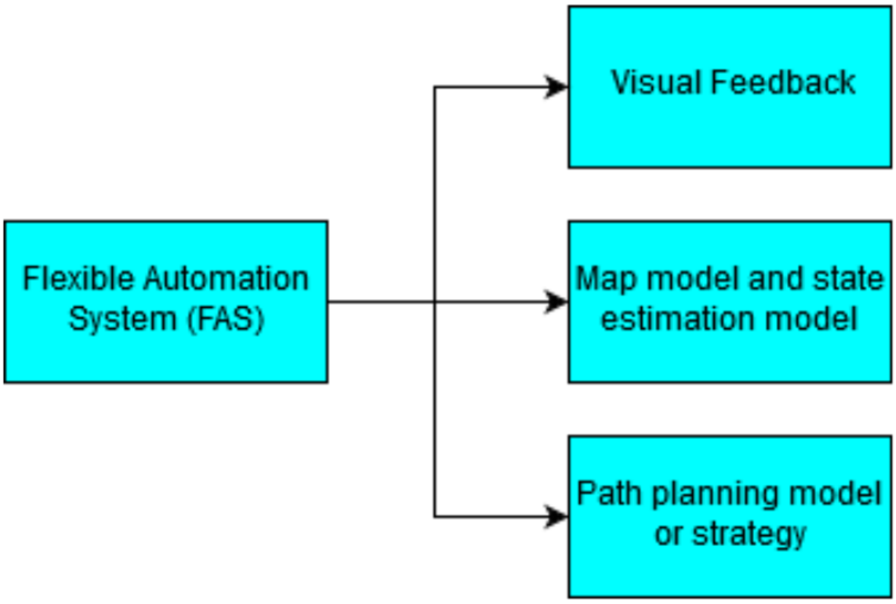

Figure 1.1: Three aspects of an FAS to maintain a safe and cost effective robotic system in a production line.

model summarized ~~by~~ Figure 1.2. A map model is a mathematical representation of an environment and state estimation model is a process of estimating an industrial robot configuration, location, velocity and acceleration of its end effector. The map model will provide the information for the FAS to manage the movement of a robot arm in its workspace based on the state estimation.

The third aspect of an FAS is the path-planning model. We regard the movement management of an industrial robot as a path-planning model The path-planning model is used to calculate an optimum way to reach a point in space without colliding with any obstructions or obstacles. The path is dependent on the information restored in the map model of the workspace.

1.1 The Motivation of Encoder-less Robot Manipulator

This thesis champions an encoderless solution to the FAS. With an encoderless solution, a manipulator has less complex design. The design will be lighter and occupy less space because the system does not require encoder units. The system construction is economical because it requires less main-

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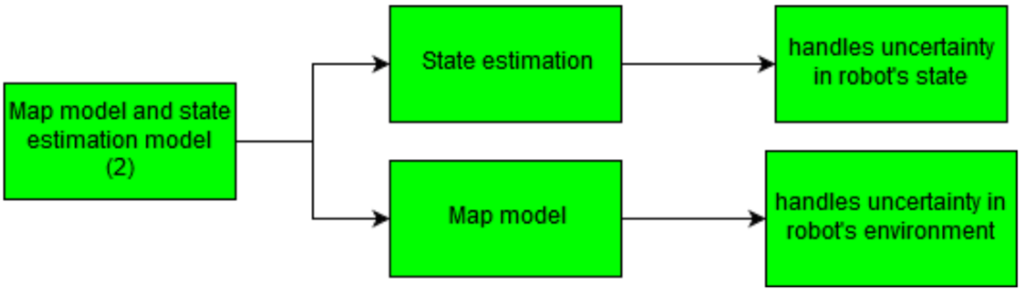

Figure 1.2: The second aspect of an FAS consist of two mathematical model that manage the uncertainty of the workspace of a robot and the uncertainty of the state of the robot.

tenance. As an example, and ABB IRB1600 has six actuators that as six encoder unit. The failure of one of the encoders can cost the owner a new set of actuator because of the control design of this system requires a tightly coupled encoder-motor electronics. A failure of one of an encoder also means the whole system will requires calibration specifically on homing calibration after the defective encoders are replaced; a high-maintenance characteristic that SME business do not favor.

1.2 The Motivation of Eye-in-Hand Robot Configuration

. One of the solution to encoderless robot system is the use of machine visions technology. The designer can consider, eye-to-hand configuration where the vision sensor is attached to an additional structure that has a vantage point of the robot manipulator and the workspace (Luo and Kuo 2016). Luo and Kuo (2016) used Kinect, a type of visual-depth sensor (RGB-D), to produce workspace model of their robot system and to identify objects in the workspace. Figure 1.3 shows their setup. The sensor can also be attached on to the robot itself: e.g. at the end-effector frame. In this research, eye-in-hand configuration is considered.

Figure 1.3: Eye-in-hand configuration that uses visual feedback enables an articulated robotic arm to identify objects in its workspace for manipulation.

1.3 The Devoid of Unified Solution for Uncertainty Management in State and Workspace of an Industrial Robot

Despite rich solution options to uncertainty of a robot state and its environment, the solutions are disjoint and performed separately. Simultaneous localization and map-building solution (SLAM), however, incorporate both the solution to uncertainty of the robots state and the solution to uncertainty of the environment into one framework. Equation 1.1 summarize the concept of SLAM:

$$p(m_i, x_i | z_i, u_i, x_{i-1}) \tag{1.1}$$

where p (also known as posterior) is the real-time process of maintaining the map of an unknown environment and estimating the current state or pose of a robot. m i is the global map model, x_i is the state estimation, z_i is the measurement or observation model or visual feedback model of the robot, and u_i is the state transition matrix or state transition model of the robot. x_{i-1} before a new measurement is taken. Figure 1.4 summarizes the arguments of equation 1.1.

In theory a SLAM solution covers the first and the second aspects of the FAS proposed in this research. Figure 1.5 articulate the relevance of SLAM solution to an FAS.

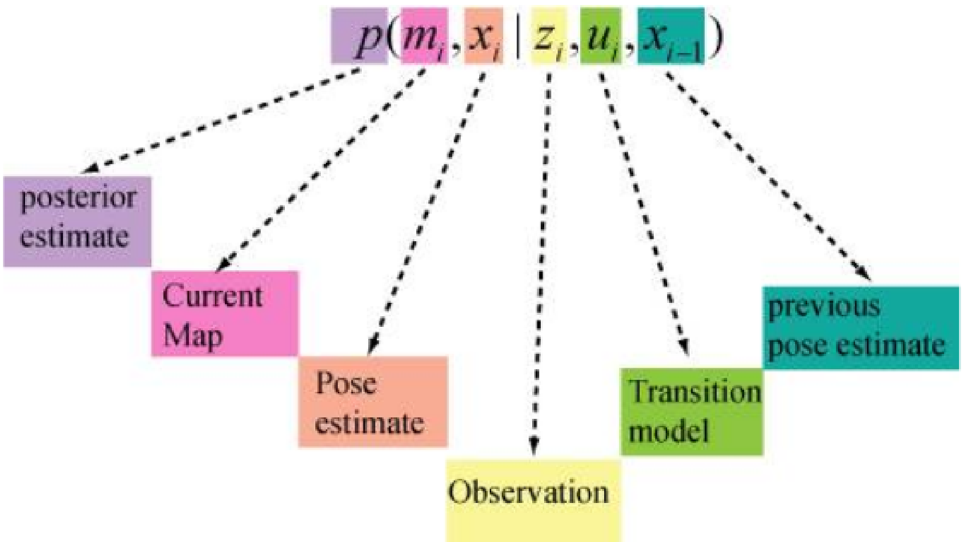

Figure 1.4: The variables parameterizing the SLAM solution

Yet SLAM has only been optimized specifically for autonomous robot to address an unknown environment. The definitive researches on the use of SLAM in articulated robot were introduced by Klingensmith, Sirinivasa, and Kaess (2016), Ito, Li, and Maeda (2020), and Li, Ito, and Maeda (2019). However, they did not consider the uncertainty of the state of the robot, the uncertainty of the robots environment, and the path planning solution in a single framework. Figure 1.6 summarizes the gap in finding a solution to a path-planning under the uncertainty of the state of the robot and the uncertainty of its environment.

1.4 Problem Statement and it's Significance

The current state-of-the-art approaches to an industrial articulated manipulator ~~lack~~ a solution that addresses ~~the high maintenance cost and~~ the safety of the system in a changing environment. In the probability paradigm of robotic system, the SLAM solutions for articulated manipulator have only addressed the issues of accuracy without tackling the high maintenance cost and safety of a robot manipulator specifically on the production set-up. Furthemore, the performance of these solutions against probabilistic path-planner has yet been reported. ~~I will attempt to reduce the complexity of managing the motion through an encoderless system for a manipulator placed in a controlled environment by coupling an existing solution for SLAM problem and an existing framework for probabilistic path-planner.~~ This attempt intend

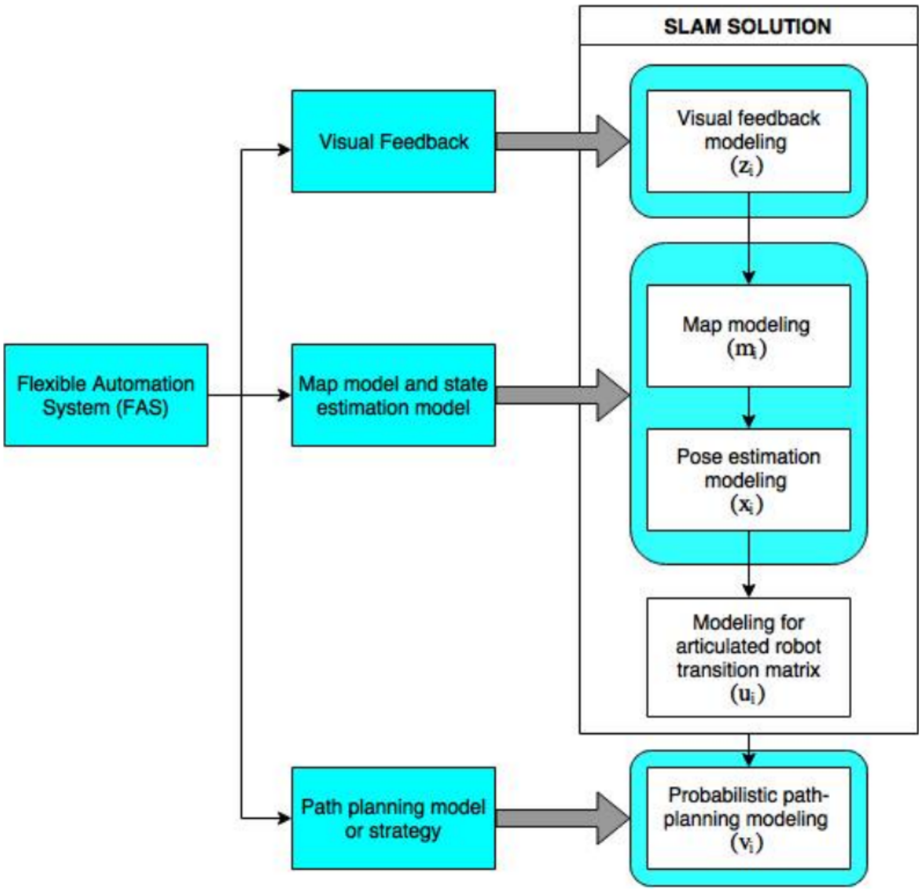

Figure 1.5: The connection between an FAS to a SLAM solution

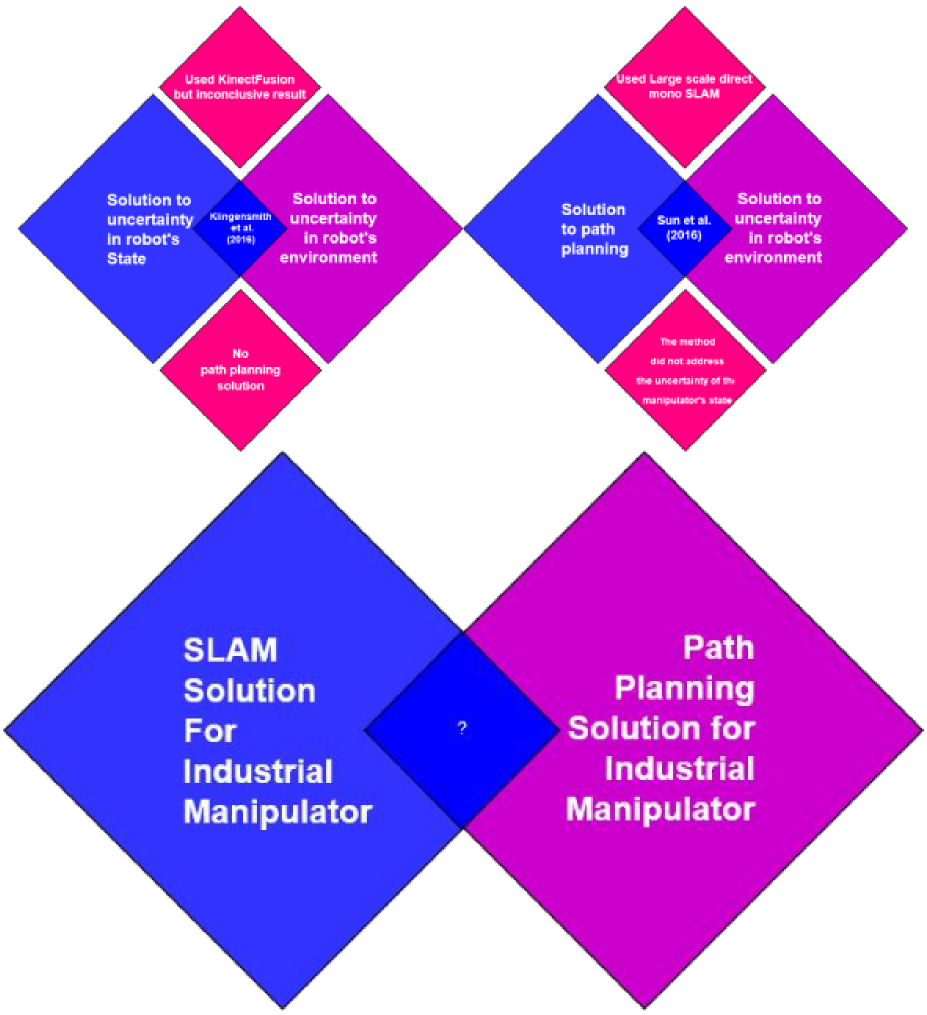

Figure 1.6: The gap of a solution to path-planning for uncertainty in the state of the robot and the uncertainty of the environment of the robot in a single framework hinder a functioning FAS in context of an industrial robot

~~to aspire flexibility and cost effective robot manipulator system for industrial purposes in SME's.~~

1.5 Research Philosphy

~~An encoderless~~ concept for a robotic arm by leveraging the probabilistic mathematical models for map of an environment, the state estimation of a robot, and the path-planning model in controlling the robot motion will decrease ~~maintenance cost of the industrial robot system without jeapordizing safety.~~

1.6 Objectives

1. To design a six-axis manipulator and build it as a prototype of a compliant (back-drivable) manipulator.

2. To simulate a moving obstacle avoidance capability using a probabilistic ~~planner or a sampling-based~~ motion planner. obstacles~~ in a simulation for the compliant manipulator.~~

3. To demonstrate the obstacle avoidance capability on the compliant manipulator hardware with a synthetic moving obstacle augmented from a simulated environment.

4. To show the feasibility of using a SLAM solution as a feedback pipeline for the compliant manipulator to validate a encoderless manipulator concept.

1.7 Research Scope

This research uses a back-drivable (compliant) articulated robot with six axes to implement the framework of a fully probabilistic strategy to path-planning and obstacle avoidance. This research only ~~use~~ an RGB-D sensor.

The dynamic environment is a non-reflective and non-specular workspace. In context of designing the workspace as a dynamic environment, the workspace is not share with another robotic arm. Instead, the workspace will be introduced with a moving obstacle. Figure 1.7 shows the scope and the considerations of this research.

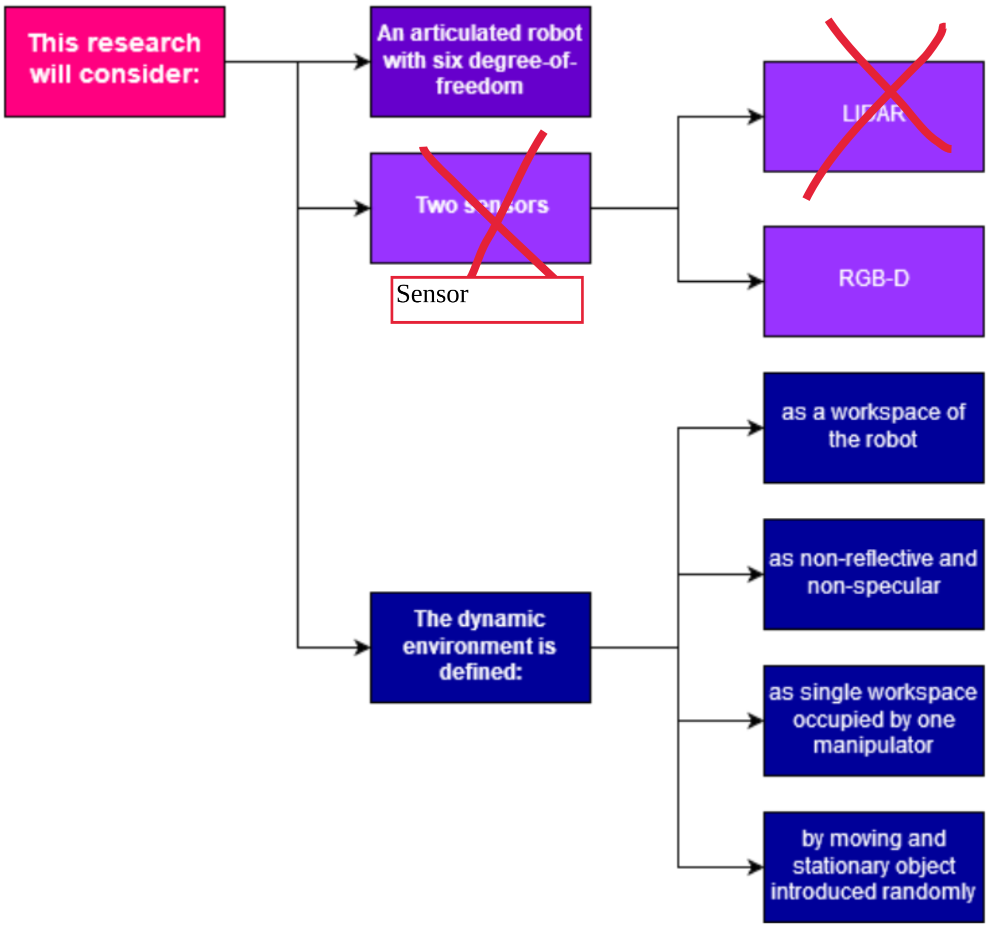

Figure 1.7: The scope of this research and its considerations

1.8 Methodology

In this research, we view the model of a robot kinematics, specifically on the task space (the end-effector frame) of the robot, $\mathcal{C}_{ee} \in \mathbb{R}^3 \times \boldsymbol{SO(3)}$ where, $\mathbb{R}^3 \times \boldsymbol{SO(3)}$ is homeomorphic to the special Euclidean group, $\boldsymbol{SE(3)}$ such that:

$$\mathcal{C}_{ee} = \mathbb{R}^3 \times \boldsymbol{SO(3)} \tag{1.2}$$

Thus, ~~since~~ all SLAM solutions for three-dimensional space output state estimation in the form of $\mathbb{R}^3 \times \boldsymbol{SO(3)}$ ~~their~~ model in equation 1.1 holds for industrial robot arm. Nonetheless, the complete solution for SLAM does not consider the path- planning model of the robot arm, specifically, the mapping of the configuration space, $\mathcal{C}^n \in \mathbb{R}^6$ into the $\mathcal{C}_{ee}$, where n is the number of rigid body in the robotic arm. Hence, I intend to investigate if a probabilistic model of a path-planning strategy can reconcile with Equation 1.1 such that:

$$p(\mu_i, m|\hat{x}_i, z_i, u_i) \tag{1.3}$$

where p is similar to the process of maintaining the map of a the workspace and estimating the state of a robot concurrently where, $\hat{x}_i$, is the state estimation pipeline of a SLAM solution in equation 1.1.

In equation 1.3, the solution incorporates both SLAM algorithm and a probabilistic path-planning model into a single framework instead of considering the SLAM solution and path-planning algorithm separately. We outline our research methodology based on equation 1.3. An overview of the research methodology against the objectives of this research is presented in figure 1.8.

1.8.1 ~~Feedback Modeling~~ ~~(z_i)~~

~~The feedback model uses only one sensor; the RGB-D sensor. This research will model the RGB-D sensor based on their statistical parameter estimation method prescribed in Iman and Rashid (2016). The data from the RGB-D sensors will represent the sensor model,~~ ~~z_i~~ ~~.~~

Move 1.8.1 to 1.8.7 under the methodology chapter.

~~1.8.2~~ ~~Map Modeling~~ ~~(m_i)~~

~~The obstacle presented to the workspace will be modeled and tracked based on the probabilistic model of the map of the environment using the octomap map model.~~

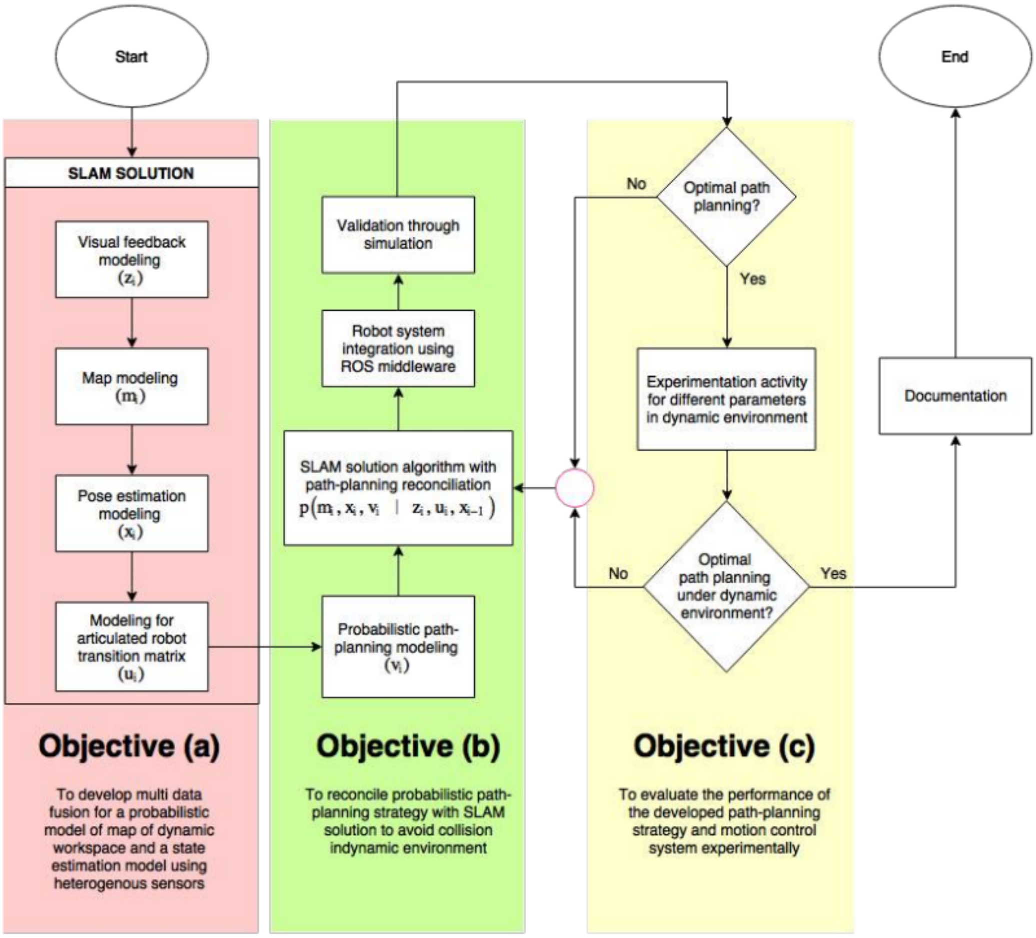

Figure 1.8: Summary of the methodology to achieve the objectives of this research

~~1.8.3 State Estimation Modeling (x_i)~~

~~The state estimation model is based on features extraction from the map model where each joints of the articulated robot arm is estimated from the visual feedback model and compared with its the planner's solution.~~

~~1.8.4 Articulated Robot Transition Matrix Modeling (u_i)~~

~~The robot forward and inverse kinematics model of the robot will be used as the process model or the transition matrix of the system. A process model or a transition model is a deterministic representation of the robots motion and configurations. We will adopt the total algebraic solution to the inverse kinemtatic delineated by Pires (2007)~~

~~1.8.5 SLAM Solution and Path Planning Model (μ_i)~~

~~Both the solution of the planner and the state estimation of the SLAM pipeline will be compared and analysis to see if it is feasible for both algorithms to be combined as a unified solution represented by the model in equation **??**~~

~~1.8.6 ROS Middleware Implementation~~

~~The mathematical models: z_i , m_i , x_i , u_i , v_i , will be programmatically translated into a Robotic Operating System (ROS) package. The ROS middleware is essential in integrating the articulated robot chassis with the mathematical model of the map, visual feedback sensor, state estimation, transition matrix and the probabilistic path-planning.~~

~~1.8.7 Validation and Evaluation~~

~~The ROS package containing the availabe path-planning strategy will then be used in a simulation using the Gazebo software available in the ROS middleware. The parameters from this simulation will be used in an experimental setup that introduces various obstacles to the workspace of the articulated robot arm. This series of experiments will determine the efficiency of various filtering and modeling techniques for the path-planning strategy.~~

1.9 The Outline of the Thesis

This thesis starts with the literature review of the state-of-the-art and the leading papers on state estimation, map-building models and path-planning in chapter **??** The readers are then introduced with the mathematical background being used in this thesis in chapter **??**

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