Chapter 71
Modelling and Simulation Platform for Chemical Plume Tracking and Source Localization

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ABSTRACT

Using autonomous robot to detect chemical emissions and track plumes caused by fire, toxic gas leakage and explosive at their early stages, and swiftly localize their sources can avoid risking human health and potentially save lives. The benefits of deploying autonomous robot(s) rather than human beings in performing such hazardous tasks are obvious. Even though using real robots to research, develop, and experiment in real environment are normally preferred, modelling and simulation are indeed sometimes better options when such as a consistent and repeatable complex environment with controllable variables (i.e. wind velocity and plume propagation in this case) for experiments is important. This chapter presents one out of many possible modelling and simulation approaches for the research related to chemical plume tracking and source localization using robots, and covers the modelling of robot, the modelling of the environment, and the integration of both to become a platform.

INTRODUCTION

Using autonomous robot to detect chemical emissions and track chemical plumes caused by fire, toxic gas leakage and explosive at their early stages, and subsequently localise their sources swiftly can avoid risking human health and potentially save lives. The benefits of deploying autonomous robot(s) rather than human beings in performing such hazardous tasks are obvious. As a result, enabling robots to possess

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such capability has been highly desirable and starting to attract research and development attentions in recent years which can be mainly attributed to the lately advances in robotic technologies to make it all possible while the international concerns and attentions with security and terrorism are getting higher.

When tracing back relevant studies in literature, it can be found that it all started in the 1970s and 1980s. By then, many investigations took place concerning the plume tracking behaviours of insects, flying and walking, through observations both in the field (David et al., 1983) and under controlled laboratory environments (Farkas & Shorey, 1972; Kennedy & Marsh, 1974) as well summarised in (Harvey et al., 2008a). For example, in (Olberg, 1983), the brain of male silkworm moth was studied to understand why and how it is sensitive to female pheromone to tracking the pheromone plume and find the location of female silkworm moth for mating. Kowadlo and Russell, (2008) summarised the behaviour of most researched insects, bacteria and animals tracking the plume until localising the source. As a result of such studies, mechanisms governing insect and animal plume tracking behaviours were deduced which later were proved to be heavily coupled with the environment conditions including time-dependent patterns of wind velocity (speeds and directions) and the concentration levels of particular stimulus, such as the female pheromone. Subsequently, in order to verify the correctness and effectiveness of the deduced governing mechanisms which many were described as if-then rules and coupled with wind speed and direction changes as well as chemical concentration level change, wind sensing and chemical concentration level sensing capabilities are seen to be necessary. To fulfil such needs, applying knowledge learned from insect's sensing mechanisms, designing and developing such sensing capabilities following pure engineering approach, or combing both approaches are all feasible options. Then, since late 1980s, publications related to gas sensor research and developments started to emerge, for example Watson (1984) presented a gas sensor based on tin oxide and the development of conducting polymer sensors (Bartlett et al., 1989). Later on, rather than using artificially fabricated chemical sensors following engineering approach, some studies adopted and connected insect antennae directly to robots to provide chemical concentration measurements. They were used to further research in mimicking insects to reproduce plume tracking behaviours (Kuwana et al., 1995; Kuwana & Shimoyama, 1998). Such live insect antennae, even though very sensitive, nevertheless can only be used for a short period of time depending on how long the living cells can survive and maintain the functionalities after being removed from insects (Ando et al., 2013). In terms of wind sensing, since the commercially available wind sensing products tended to be too bulky for being implemented on small robotic platforms for this field of research, purposely designed and smaller sized wind sensors were developed, which can be found being implemented in various studies (Chapman et al., 2000; Harvey et al., 2003; Laghrouche et al., 2005; Lu & Ng, 2006; Lu & Qi, 2007; Russell & Kennedy, 2000). With suitable wind sensors and chemical sensors made available, systematic studies to better understand the relations between the governing mechanisms of insects and the associated environment conditions can thus be carried out to harvest more knowledge for possible engineering benefits.

Since 1990s, numbers of studies regarding robotic plume tracking (or in some literature, it is called 'tracing') started to appear which mainly focused on verifying and/or implementing either the governing mechanisms deduced and maybe modified from insects and animals or the governing rules designed from engineering perspectives, for example (Harvey et al., 2008a; Ishida et al., 2006; Kuwana & Shimoyama, 1998; Liu & Lu, 2009; Martinez, 2006) respectively, of which many have been summarised in (Kowadlo & Russell, 2008). Since then, there have been ever increasing numbers of studies adopting robots equipped with different numbers of wind sensors and chemical sensors which were arranged differently. These studies also include the use of single, multiple, in formation, not in formation, or swarm