Chapter 2

State of the Art

In this section, we provide some general insight in the world of human - robot interaction and swarm robotics. We then review the literature of human-swarm interaction.

2.1 Human - Robot Interaction

Human - robot interaction has become a subject of great importance. A lot of research has been done in this field recently in order to mimic the human communication behaviours in different circumstances. One of the most interesting examples is Minerva (Thrun et al., 1999). Minerva is a tour-guide robot that educates and entertains people in public places. It has a motorised face to imitate human emotions. It was tested in a museum where it successfully performed what it was created for while learning. Dautenhahn et al. (2006) studied how a robot should best approach and place itself relative to a seated human subject. They performed experiments where a human asked for an object that would then be fetched by a robot. The robot would come to the human using different approach directions. The results reveal that most humans disliked the frontal approach and preferred to be approached from either the left or the right side. Itoh et al. (2006) studied the negative physical and psychical effect of robots on humans. Their study aims to complete other studies that only subjectively measured these negative effects by questionnaires. They built a device to measure physiological parameters such as respiration, heart rate, perspiration and pulse wave, and arm motion to obtain an objective measure of the effects of robots on humans. Using this device, the robot was able to react to the stress of the human and move accordingly in order to decrease the stress. Bethel et al. (2009) investigated on non-facial and non-verbal methods of affective expression for enabling social interaction in appearance-constrained robots and found 5 main methods: body movements, postures, orientation, color, and sound. Example of appearance-constrained robots can be found in search and rescue, law enforcement, and military applications. They conducted a study involving 128 participants in a confined-space simulated disaster site with the robots interacting in the dark. *'Statistically significant results indicated that participants felt the robots that exhibited affective expressions were more calming, friendly, and attentive, which improved the social human-robot interactions'* (Bethel et al., 2009).

The objective of this project is to protect a human from dangerous areas using robots. For this purpose, the robots have to recognise and locate the human. Several solutions have emerged trying to solve that problem. However only few of them considered the sensor to detect the human as being close to the ground. These solutions rely either on 2D laser range data on an horizontal plane, or RGB-D data. RGB-D (Red Green Blue-Depth/Distance) associates the usual video stream to a 'depth' channel (Wikipedia, 2014). Gritti et al. (2014) propose a new robust solution for people detection and tracking using Kinect (Microsoft, 2015) or Asus Xtion (Asus, 2015). The floor must be flat. It uses a statistical classifier trained with a big dataset containing real-world data. After classification either as human leg or obstacle, the data is fed to a tracking algorithm to track people. Such lasers are very expensive, and at the time of realising this thesis it was not possible to use Kinect sensors on the robots. As robotics swarms imply the use of many robots, buying one of these sensors for each robot is too expensive. Thus we have to implement our own solution based on the sensors available on the robots that we have.

2.2 Swarm Robotics

For Şahin (2005), swarm robotics is defined as *'the study of how large numbers of relatively simple physically embodied agents can be designed such that a desired collective behaviour emerges from the local interactions among agents and between the agents and the environment'* (Şahin, 2005). These groups of agents do not depend on any external structure or centralised control (Dorigo et al., 2014). The development of swarms of robots rely on the principles of swarm intelligence. Swarm robotics can be separated from other robotic studies by the following characteristics (Brambilla et al., 2013):

- Robots are *autonomous*;
- Robots evolve *in the environment* and can interact with it;

- Robots' interactions are *local* (sensors and communications);
- No *centralised control* or *global knowledge*;
- Robots *cooperate* to achieve a certain goal.

As in swarm robotics, one is always looking for *robust*, *scalable* and *flexible* systems, the main source of inspiration is the group of social animals (e.g.: ants, birds, fishes). When some of these simple animals gather in groups, they are able to perform tasks that could not be achieved individually (collective behaviour emerges from local interactions). Below are listed the definitions of these three terms (Brambilla et al., 2013):

Robustness: Resistance against *loss of group entities*. One can increase it by adding redundancy or remove the need for a leader.

Scalability: Low variation in the performance of a system with respect to the *size of the system*. It can be increased by encouraging local interactions, such as sensing and communications.

Flexibility: Low variation in the performance of a system with respect to the *type of environment or the task.*

With these definitions in mind, we can explain swarm engineering as:

> *'Swarm engineering is an emerging discipline that aims at defining systematic and well founded procedures for modeling, designing, realizing, verifying, validating, operating, and maintaining a swarm robotics system.'*
> *- Brambilla et al. (2013)*

In this thesis the robots have to protect the human. We opted for a solution where the robots escort the human. For that purpose they need to stay close to him/her. The group composed by the human and the robots have to move in a coordinated manner. The scientific term for this coordinated behaviour is *flocking*. Many examples can be found in nature, e.g. birds, fishes. In nature this behaviour offers many advantages. The most common approach for implementing a flocking behaviour is virtual physics design. One can also obtain these types of motion through artificial evolution (Brambilla et al., 2013). Reynolds (1987) was the first to propose a model for flocking. It was meant for computer graphics applications. With only 3 simple rules that every agent in the swarm has to respect, he was able to obtain realistic simulated swarm behaviours. The 3 rules are as follows:

Separation: Each agent tries not to be too close from its neighbours to avoid collisions.

Alignment: Each agent changes its heading to the average heading of its neighbours.

Cohesion: Each agent tries to centre itself at the average position of its neighbours.

Baldassarre et al. (2003) used evolutionary techniques to develop collective flocking behaviours. They demonstrate that these techniques are a powerful method for implementing collective behaviours. One of the most effective strategy that arose contained forms of 'situated specialisations'. Robots with identical evolved controllers have behaviours that depend on the circumstances. They think this is caused by the objective to reduce the interference between the attraction to the target and the need to maintain an aggregation state. Thanks to these specialisations, they observed that one of the robots was leading the way to the target while the others just tried to stay close to it. This is close to the idea behind the solution we want to implement.
Turgut et al. (2008) proposed one of the first implementations of Reynolds' (Reynolds, 1987) behaviour on real robots. Each robot knows the heading of its neighbours and their distance via a virtual heading sensor and infrared sensor respectively.
Çelikkanat and Şahin (2010) investigated on the very important problem of the control and guidance of a swarm of robots: how to control the swarm and to what extend it can be controlled. They guided a swarm of robots by controlling a minority of the agents inside the swarm: 'informed robots'. 'Naive robots' only consider the flocking objective while the 'informed robots' also took into account the direction orders given by the operator.
Ferrante et al. (2012) focused on motion control. They implemented a new way to translate the output of the flocking rules into wheel speed. They made the speed of the wheels proportional to the norm of the resulting direction vector. This technique can be implemented on the simplest robots, even those which cannot detect neighbours heading. They added a few 'informed robots' in the swarm and showed that the swarm could travel longer distances using this norm dependant technique instead of the constant speed technique.

2.2.1 Human - Robots Swarm Interaction

Human - Robotic swarm interaction is the study of how humans can interact with a swarm to control it and receive feedback from it (Brambilla et al., 2013). A proper feedback is needed by the operator in order to make the right decisions. Since swarms must ideally be autonomous and make decisions in a distributed way, it is difficult to insert a communication with a human operator in the system to gain control.

Currently, little attention has been devoted to the study of the interaction between humans and robotic swarms, how one can send instructions and receive feedback. One of the challenges in human-swarm interaction is the difference in perspective between the swarm and the human operator. The human only observes the global collective behaviour, not the local interactions or individual behaviours driving the robots. The simplicity of the hardware found on the robots, or the efficient synthesis of all the information sent by the robots (i.e., feedback) are also challenging. Most of the existing works in the literature present a major disadvantage: they require an extra layer between the group of robots and the human. This requirement might not always be satisfied when we remember that swarms like this are mostly destined to evolve in an unknown environment. The monitoring equipment necessary to operate the swarm may not be safely deployed. Furthermore, a synthesis of all the local information pieces must be done in order to provide an understandable state of the system to the human. This synthesis involves modelling, additional overheads and perhaps heavy computations, and the gathering of all information at a central point (eliminating by the way the distributed and decentralised properties of the swarm system) (Podevijn et al., 2012).
Daily et al. (2003) used a head-mounted display and augmented reality to add information right on top of the robot in the environment itself, suppressing the need for an additional display. Baizid et al. (2009) proposed a platform to interact with multiple robots simultaneously through a graphical user interface, or a head-mounted display, in virtual reality. They also studied how virtual reality abstraction affected the human perception and cognitive capabilities, i.e, they created a virtual environment by filtering useless information. McLurkin et al. (2006) developed an centralised graphical user interface taking inspiration from real-time strategy video games, where one must control armies. They also imagined a feedback approach based on LEDs and sounds. The robots transmit their internal state by applying to their LEDs and sound system a defined pattern, recognisable by the operator, now able to quickly understand the state of the swarm without looking at a supplementary interface.
Podevijn et al. (2012) argue that self-organised mechanism, as those ruling the be-

haviour of the swarm, should be used to provide feedback to the operator. They suggest that the best entity which could communicate the status of the system and the whole swarm is the swarm itself. They performed experiments using colour feedback to distinguish different internal states and split the swarms into groups to tackle different tasks.

As swarm robotic systems are mostly destined to operate on risky floors, unknown environment, it would seem logical to consider their application in exploration and/or protection missions. However, at the time of writing this thesis, we could not find any study on the subject. Exploration experiments never included a human, or other living organism. The objective of this thesis is to address this lack of study by designing and implementing a protective behaviour executed by a robotic swarm.
The human operator is here part of the swarm system. The swarm has to protect him by preventing him from going into dangerous areas, in the same way a group of bodyguards protects someone. The swarm has to follow the operator anywhere to ensure permanent protection.
We believe this work to be important since it might open doors to new types of applications of swarm robotics: human protection, escort or swarm turn-by-turn navigation.