

Exploring Negative Emotions to Preserve Social Distance in a Pandemic Emergency

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Abstract. In this work, we present a multi-agent robotic system which explores the use of unpleasant emotions triggered by visual, sound and behavioural affordances of autonomous agents to interact with humans for preserving social distance in public spaces in a context of a pandemic emergency. The idea was born in the context of the Covid-19 pandemic, where discomfort and fear have been widely used by governments to preserve social distancing. This work does not implicitly endorse the use of fear to keep order but explores controlled and moderate automated exploitations. On the contrary, it deeply analyses the pros and cons of the ethical use of robots with emotion recognition and triggering capabilities. The system employs a swarm of all-terrain hexapods patrolling a public open space and generally having a discrete and seamless presence. The goal is to preserve the social distance among the public with effective but minimal intervention, limited to anomaly detection. The single agents implement critical tasks: context detection strategies, triggering negative emotions at different degrees of arousal using affordances ranging from appearance and simple proximity or movements to disturbing sounds or explicit voice messages. The whole system exhibits an emerging swarm behaviour where the agents cooperate and coordinate in a distributed way, adapting and reacting to the context. An innovative contribution of this work, more than the application, is the use of unpleasant emotions affordances in an ethical way, to attract user attention and induce the desired behaviour in the emergency. This work also introduces a method for assessment of the emotional level of individuals and groups of people in the context of swarm agents. The system extends the experience of the *gAItano hexapod project*, an autonomous agent with image detection and planned object relocation capabilities.

Keywords: Affective computing · Emotion affordance · Autonomous agents · Swarm behaviour · Social distance · COVID

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1 Introduction

1.1 Background and Ethical Goals

During a pandemic emergency, an exceptional and sometimes surreal situation is present, where the government has to set up and exploit an effective system for social distancing for everyday activities, in a critical equilibrium between lockdown and economical surviving. The perfect environment is not applicable, but strict rules have to be given, especially in a previous phase, where the viral contagion behaviour and epidemiological characteristics of a new disease are still not explicit. Sometimes, preventing a few contacts will lead to avoiding several deaths and a substantial economic loss [1, 2].

In such a situation, during the 2020 Covid-19 spread, for instance, several countries decided to lockdown any non-essential activity [3], and to apply strict rules of social distancing for the remaining [4]. To convince people complying to such rules, sometimes unclear, and often generalised, governments decided to use mass media [5], military forces or even robots heavily to induce in citizens the fear to be caught in illicit activity, thus being fined or threatened to stand trials.

For instance, in Italy several extreme cases can be listed about very expensive or stunning approaches used to frighten people even in less dangerous situations, e.g., flying a police helicopter at low altitude on the shore where a couple had secluded themselves, to splash and frighten them to make them go home [6]; deploying an entire Carabinieri squadron to block a runner on the beach [7]; pushing teenagers or elderly caregivers on the ground, handcuffing them and then taking them to the station to be identified, only for hesitating to provide the required documents and written self-declaration for the activity [8, 9].

Such heavy approach instilled a general fear and tendency to overestimate the rules, in order to avoid as much as possible any case of transgression. As a side effect, it also induced a fear syndrome, often leading to panic, that resulted in trauma in many people [10], with a significant increase in requests for psychotherapeutic assistance during phase two when the lockdown was reduced.

The Italian company Elettronica Cortesi proposed to clients an Artificial Intelligence (AI) tablet with a thermal scanner and facial monitoring to check if the person is correctly wearing a protective mask [11]. Also, the resort city of Cannes on the Côte d'Azur has trialled an AI software for digital surveillance, installed at outdoor markets and on buses, to check people wearing masks, keeping privacy protection [12].

A four-legged robot dog named Spot was set to help social distancing efforts in the Singapore national park of Bishan-Ang Mo Kio, patrolling the area running and looking for people walking together. The yellow and black canine robot with four articulated legs and an injection-moulded hard plastic shell, part of a trial by Boston Dynamics, spawned awe and fear at the same time [13]. Spot runs in the park and gives vocal warnings to visitors to observe the distance measurements, equipped with cameras to assess the correct distance between people and measure their number in the area.

In a pandemic emergency, AI and robots can have a crucial role for some extents, reducing the exposure of law enforcement and healthcare workers to the possible

contagion due to physical contacts, given some ethical constraints, e.g., to avoid enabling them to recognise individual citizens or retain personal data. In China, for instance, the decision of the President to use drones to control and identify people breaking the Covid-19 social rules to arrest them raises some ethical concerns for personal privacy and impacts the people's negative perception of the relationship between the State and citizens.

Although robots can be expensive to design, develop and test, such an effort can be done once for many applications, and be more than convenient comparing to the personal risk or the economic loss due to law transgression and thus pandemic spread [14]. Since the fear of the actor triggering the negative emotion can be permanent and tend toward generalised anxiety, an equally relevant point is that it is healthier if the subjects of such action are not human: a robot with an ad-hoc appearance, used only in the specific context, could replace the fear for people with an eerie sensation limited to a specific device, which will not be present in everyday life, thus avoiding a persistent trauma.

1.2 Previous Works

Affective computing is a research area of growing interest, in particular for emotion recognition and triggering. The ability to assess the emotional content of a situation can help to improve the effectiveness of applications in a vast amount of scenarios, e.g., the analysis of trends and information diffusion in social networks [15], recommender systems [16], image recognition [17], semantic context generation [18], social robots [19], and more generally in human-machine interfaces. Sentiment analysis is a widely investigated topic [20]: the aim is to produce semantic annotations focusing on a trivial classification of the stance (i.e. the sentiment) towards an object, only according to its positive, negative or neutral polarity. Emotion recognition works at a deeper level because it is aimed at quantifying the emotional load, concerning various emotions conveyed, e.g., by multimedia objects [21].

Part of the definition of a framework performing semantic analysis is the choice of a proper knowledge source. Web-based similarity measures [22], for instance, evaluate the similarity of terms from the number of occurrences and co-occurrences of such terms in a document corpus, e.g. the documents indexed by a search engine. Such corpora are updated continuously, reflecting the natural evolution of knowledge, and thus constitute an excellent base for real-time applications.

Fundamental studies carried out by psychologists led to the development of various models of emotions, e.g. Ekman, Plutchik, and Lovheim [23]. Such models encompass and reduce the full range of complex human emotions to sets of basic emotions which prove general for all human beings, despite their cultural origin, age or gender. Emotion models induce a numerical representation, often binary, for an object (e.g., user face [24], multimedia document), consisting for instance in a vector of emotions [25] which quantifies, for each emotion of the model, the emotional load associated to the object.

The context of autonomous agents, which could be able to detect and trigger emotions based on a complex multi-source affordance model [26], requires to focus on the individual agent first, and then on the interactive cooperation and reaction of the

agents as a swarm, which can be seen as a collective individual or team. The individual autonomous agent in this context is a hexapod robot. This type of robot is particularly suitable for open space outdoors patrolling, because of its capability to move overcoming obstacles and adapting to various terrain types and slopes, thanks to the six-legs design with 18 degrees of freedom. Among others, hexapods usually show a good appearance compared to other insect-looking or animal-appearance robots and their natural and smooth movements allow them to be accepted in human environments where sensible people usually do not accept robots, feeling uncomfortable in their presence. The MSR-H01 model used in the gAItano Hexapod Project [27] on which our model is based, is usually accepted as "cute" or "cool", compared to other "scary" robots. In this project, we aim to add "scary" capabilities, evidenced in an adaptive level, only in case of law transgression, to maintain order and induce eventual trespassers or offenders to restore a legit behaviour in an emergency related to pandemics or other critical situations where social distancing may be a matter of life or death.

2 From GAItano, the Intelligent Hexapod Robot, to the Swarm

The swarm design starts from the *gAItano Hexapod Project* [27], based on the *MSR-H01* robot, created by Mycromagic Systems, measuring a few tens of centimetres (i.e., $\sim$1 foot). Our vision cannot base on the original gAItano, because tests show that a small hexapod is considered cute and does not induce the required awe and respect. Thus, considering the average distance considered safe worldwide, we set the hexapods size to a diameter of 1.5 m (i.e., $\sim$5 feet). This size is useful as a baseline reference for social distancing.

The hexapod as a type of robot is particularly suitable to move in several directions on any terrain, including stairways and steep or bumpy trails. The material should be light for energy saving: a 3D-printer could be the best tool for a cheap swarm creation, also considering that several free 3-D models for printing hexapods are available on the Web, and the hexapod architecture is suitable to carry much more weight than the robot weight, including micro-controller, servo motors, batteries, sensors.

The original gAItano that we can take as a model is a six-legged hexapod robot, which architecture and software allow smooth movements with 18 grades of freedom for all the legs, and whose goal is to relocate objects in the environment, based on some positioning constraints to match. The robot could patrol an area with a crab walk, look at the environment, identify unordered objects, and push them in the right position. Thus, the underlying software that we previously developed already allows the robot to move in an environment of unknown size, and perform autonomous actions based on AI. If anything changes in the environment during the walk, gAItano can adapt his decisions in real-time. The visual recognition includes coloured blobs recognition. The formal definition of the goal of gAItano is the following: given a real-world (in a desirably limited, but potentially infinite area) where there are objects constituting landmarks, patrol one side of the area with respect to the landmark, keeping it free from objects, thus pushing eventual objects in another side of the area.

gAItano can be defined as a rational computerised agent:

- *autonomous*, or semi-autonomous when remotely controlled through Android or an electromyographic armband;
- *reactive*, since he chooses actions basing on perception;
- *based on a model*, because it keeps the state of visual elements of the environment;

The environment for the hexapod is:

- *partially observable*, with the unique sensor -a camera- providing a partial view, even when the swarm provides additional information;
- *stochastic*, because in the real physical environment unexpected events can happen, e.g., gAItano may accidentally hit an obstacle while pushing an object, a human agent may move unpredictably during the patrol execution;
- *semi-episodic*, since the agent acts mainly on perception and only in few cases on previous ones, except for a few sequential actions such as coming back to the patrol state or following an intervention plan;
- *static*, or *semi-dynamic* in case of human intervention;
- *continuous* both on perceptions and actions;
- *multi-agent*, because of the swarm and of human intervention that can have *collaborative* nature (e.g. when the human emergency team arrives) or *competitive* (e.g. when the human break rules or try to oppose to the robot).

Our swarm of hexapod agents starts from gAItano to design the new hexapods, which have a standard mechanical structure allowing all-terrain movements, including walking on paved roads, lawn or mud. A 360° camera allows to monitor the surrounding area; connectivity can be used to alert other hexapods or law enforcement patrols if a positioning system is available. The hexapod is also provided with lights and sound emitting devices, and it can express some gestures and behaviours, e.g.:

- body shaking/kneeling;
- rising or moving/waving single legs, independently from walking;
- lights turning on/off;
- emitting sounds/voice.

Different gestures can express different intensities using, e.g., the pace and amplitude of shaking/waving, the frequency and intensity of flashing lights and sounds.

3 Negative Emotions Affordances

The most influential models of emotions developed in psychology [28, 31] are the Ekman, Lovheim, and Plutchick models, characterised by the basic idea that any emotion perceived by a human can be expressed by a combination of basic emotions, eventually appearing in different arousal/intensity.

$\boldsymbol{E_{Ekman.}}$ = *[anger, disgust, fear, joy, sadness, surprise]*
$\boldsymbol{E_{Plutchik}}$ = *[anger, anticipation, disgust, fear, joy, sadness, surprise, trust]*
$\boldsymbol{E_{Lovheim}}$ = *[anger, disgust, distress, fear, interest, joy, shame, surprise]*

In our system, some elements are worth to point out:

- the *quantitative aspe*ct of basic emotions, i.e. emotions can appear in different arousal levels;
- *the polarity of the emotion*, i.e. negative or positive;
- the *(re)action* induced on a human by the emotion, i.e. attraction or repulsion.

In our application context, we can consider the positive/negative *polarity* of emotion as connected with the comfort/pain experienced by a person. According to this point of view, in the Lovheim model *anger, disgust, distress, fear, shame* can be considered negative emotions, while *interest* and *joy* convey positive emotions; in Plutchik *anger, disgust, fear, sadness* are negative, while *joy and trust* are positive; *anger, disgust, fear* and *sadness* are negative in Ekman, in contrast to *joy*. The fact that most emotions have a negative polarity can rely on the evolutionary role of emotions as low-level reactive mechanisms to improve individual survival in situations of danger or risk [29].

Reactions induced by the emotions are, generally speaking, determined by their polarity, i.e. a positive emotion is more likely to be attractive, desirable to follow. In contrast, negative emotions are more likely to generate a repulsive behaviour, a "fight or flight" reaction inducing either contrasting or escaping from the situation which triggered the emotion. Besides the initial physical reaction to the emotion, which includes several well-known variations in parameters, e.g., blood pressure, heartbeat, skin hydration, the reaction at a higher abstraction can be generated by a mixed emotional-cognitive level, e.g., deciding actions which aim to remove the cause of the events triggering the emotions.

The system can be easily adapted to complex models of emotional affordances. Different approaches may include the use of language-based interactions (e.g., text and voice recognition, lip-reading), visual recognition (e.g., face and gestures), and sensors (e.g., skin hydration, heartbeat). Some techniques may be more challenging than others to use in our use case because they require contact, which would need additional hygiene policies. Other sensors are more suitable than others, e.g., sensors of movement, proximity, infrared light to recognise emotions from the natural heating of different parts of the body. In particular cases, ad-hoc devices, e.g., wearables, myoelectric armbands, personal mobile devices such as smartphones, may be an additional support.

4 Swarm Distributed Behaviour

The goal of the hexapod swarm is to maintain a safe situation concerning the people behave in their area of interest or restore safety when it is violated or threatened. In the latter case, the hexapod is firstly attracted by the group of people, then gradually checks the situation and decide if it has to intervene.

Each hexapod is characterised by three primary states:

A) Random Patrolling (RP)
B) Rest Idle (RI)
C) Alert/Intervention (AI)

Transitions between states are shown in Fig. 1.

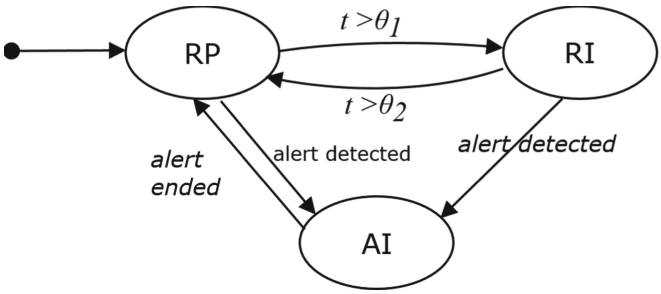

Fig. 1. Transitions between primary states of the hexapods.

4.1 Patrolling State

A hexapod is continuously monitoring the area of interest, detecting eventual violation of safety distance and requirements (e.g., wearing a mask, avoiding contact), and the position, direction and state of other hexapods in view.

The *patrolling action* consists of the hexapod exploring the area with a random walk, driven by the following behavioural rules:

- *Intra-hexapod distance*: maintaining a minimum distance from the other hexapod helps to distribute the walks evenly in the space.
- *Preference for unexplored areas*: choosing unexplored areas in case of parity of evaluation helps to distribute the walks evenly in time.
- *People-hexapod distance*: maintaining a minimal distance from people guarantees discreteness and adds value to the directional action.

The emerging trend of such rules is that hexapods spread uniformly in the surveillance area, maintaining background positions to people. The expected result of patrolling is not only to monitor actual threats proactively but also producing a deterrent effect.

4.2 Idle State

While it is patrolling with no alert after a given time threshold θ_1, the hexapod can stop and rest in an *idle state*, where it continues monitoring the environment from a fixed position without moving (i.e., resting position, energy save). On the other hand, if it remains in the RI state for more than a time interval θ_2, it resumes the RP state.

Threshold θ_1 and θ_2 are determined by a function of time spent in AI states in the previous time units. The decision of moving to RI state is randomised and penalises the presence of other idle agents in the area. If any anomaly is detected while idle or intervention is requested by other hexapods, it moves directly to AI state.

The purpose of RI state is to reflect the fact that after a given time patrolling with no problems detected, the hexapod swarm can move to a more understatement and less

energy consumption behaviour; on the other hand, a longer *idle state* could more probably miss detecting violations in other areas, which is the purpose of θ_2. Statistics on the global idles states can help the organisation to optimise the cardinality of the swarm.

4.3 Alert State

When the hexapod detects a potentially critical situation (i.e., potential crowds, violation of social distancing policies) in its area of interest, it checks if the information is sufficient to act. If more information is needed, the hexapod can decide to:

I) ask information to other hexapods in a closer position to the people;
II) approach the position where the people behaviour is potentially dangerous, to collect more evidence.

If intervention is needed, the hexapod should evaluate:

- its possible actions: e.g., move towards the target, use a signal, increase the signal, gently push a person, call the human emergency team;
- the ongoing activity of other hexapods: e.g., if other hexapods are already directing to the same target and their activation level;

then choose if the other hexapods action is already sufficient, or if its intervention is needed. If other hexapods are directed to the same target, the impact of their actions on the situation are evaluated based on the people reaction.

When the hexapod is intervening, various individual actions can be exploited. E.g., indirectly signalling to the people the violation adapting its appearance to trigger negative emotions (e.g., with an alarm sound, with gestures such as waving legs, with flashing lights), at an appropriate level (e.g., increasing volume, gesture extent, lights colour and pace) or directly signalling with a voice message, a gentle push, opposing to a people movement standing in the path. In some cases, the hexapod can intervene as a swarm, coordinating or synchronising actions.

4.4 Critical Situations

Examples of critical situations can be:

- the *low distance within two people* in a queue: intervention of an individual hexapod standing between the two;
- the *low interpersonal distance in a group* (muster or crowd): intervention of more hexapods (swarm) signalling the violation;
- *dangerous people* (individual menace threatening others, e.g. removing the mask when a mask is required, approaching other people in a small place): intervention of a swarm of hexapods, to surround the person and wait for the human emergency team;
- *people needing help*, e.g., panicking inside a crowd, shouting or fainting: intervention of a swarm of hexapods, to surround the person (to contain or protect) and wait for the human emergency team.

To evaluate the situation and to act appropriately, the intelligent hexapod control includes the following variables: emergency level, intervention type, distance to targets, number of hexapods in the area, signal level, signal type, object/people tracking.

The hexapod behaviour in the *alert state* is summarized b the following rules r1-r4:

```
r1) if (Anomaly(target) = uncertain && AgentsCloser(target) → ask(target, AgentsCloser(target))
r2) if (Anomaly(target) = uncertain && emply(AgentsCloser(target))
→ approach(target)
r3) if (Anomaly(target) = true && (ExpectedEffects(OtherAgents) > AnomalyTarget.level) → Monitor(Area)
r4) if (Anomaly(target) = true && (E = ExpectedEffects(OtherAgents) < AnomalyTarget.level = A) → DecideActions(-target,A-E)
```

where *r1* and *r2* characterise the behaviour for an uncertain level of anomaly detection, i.e. request info from other agents or collect evidence autonomously. Rules *r3* and *r4* evaluate expected effects of other agents actions concerning the intervention level required by the detected anomaly. If the expected effects due to the observed actions of other agents is considered a sufficient answer, then the agent does not act, and keeps monitoring the situation; otherwise, it passes the control to *DecideAction(target, level),* where the *target* and the expected *level* of affordance increment by the effect of the action are given.

The kernel of *DecideAction(target, level)* is a series of functions, see Table 1, which, depending on agent and target position, estimate the negative affordance level increment produced by executing that action in the current state. For instance, turning the lights on from a position where lights are not visible, e.g., behind the target, produces a smaller effect than turning on sound emission, provided the sound is loud enough to be heard from target distance.

Table 1. Functions used in DecideAction implementation

FunctionName: *parameters* → + *affordanceLevel_increment*
turnOnLight: target.position → + affordanceLevel$_{turnOnLight}$
flashLight: frequency, pattern, target position → + affordanceLevel$_{flashLight}$
turnOnSound: mode, intensity, target.distance → + affordanceLevel$_{turnOnSound}$
moveToward: target.position → + affordanceLevel$_{moveToward}$
waveLeg: frequency, position → + affordanceLevel$_{waveLeg}$
shakeBody: frequency, position → + affordanceLevel$_{shakeBody}$
combinedActionsAffordance(ownActions, ExpectedEffects(OtherAgents)) → +affordanceLevel$_{totalAffordance}$

Finally, the function *combinedActionsAffordance* evaluates the combined actions affordances concerning actions of the considered agent and actions of other agents

observed in the area. The effect of different affordances is not linearly additive. For instance, increasing the sound has a lower effect when the sound is already on, and shaking the body or waving legs when the lights are already flashing with high frequency is not probably producing any significant increment of effects on the target.

Similarly, if the agent is the only one moving toward a target, the affordance of its action is very strong if the agent contributes to surround a target, resulting in a secure threatening effect. On the other hand, a single agent moving toward a target, in whose direction a big swarm is already moving, has a neglectable effect.

4.5 Swarm Reinforcement Learning

The *DecideAction* activity is initially assigned with expected values in term of effects of actions on the observed anomaly situation. Since the real case could be different from the expected one, the level of anomaly could not be reduced if the affordance level is lower than those calculated in the functions of the *DecideAction* activity.

It is straightforward to interpret as an immediate reward the post-action observations about the previously detected anomaly level, i.e. if and how much the affordance level is reduced. Such a reward can be used in Q-learning module [30] to improve the policy for agent behaviour. The *(state, action, reward)* information collected by pre/post action observations is submitted to the Q-learning component, shared by all hexapod agents to learn the optimal policy. The learned policy is periodically updated on the hexapods (see Fig. 2), whose behaviour is thus able to adjust the unavoidable biases introduced by the *DecideAction* functions. Evaluating the effects of actions on the critical situation detected and adapting to people reactions, e.g., when people get used to the hexapods actions, their affordance level reduces, as well as the improvement of a critical situation. We decided to allocate the learning module in a separate shared unit both for computational reasons, i.e. quick reactive decisions required onboard rather than time-consuming online learning and to collect a more extensive set of training data from different hexapods episodes, which avoid learning biases due to a single-agent history.

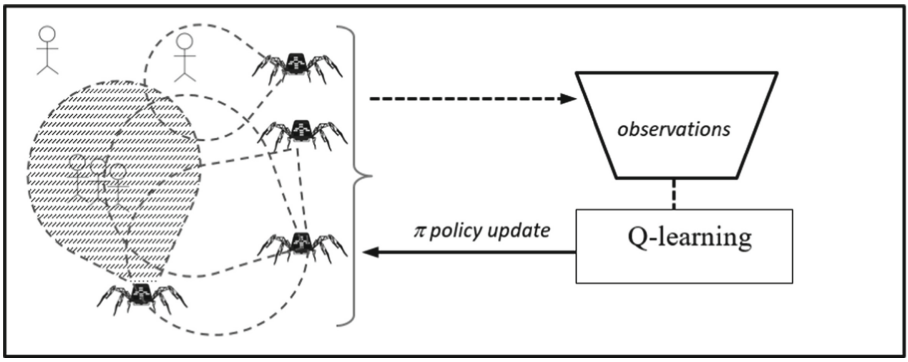

Fig. 2. Anomaly detection, actions and reinforcement learning

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