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doi:10.15199/48.2023.08.06

Social robot response to negative emotions as a PDDL planning problem in the presence of uncertainty

***Abstract**. We propose to use automatic scheduling in the presence of uncertainty methodology to analyze the emotional state of a person and possible responses of a social robot. The emotions considered were: Sadness, Fear, Anger, Disgust and Contempt. The scenarios considered include modelling uncertainty in emotion detection. The result of the work is a set of two planning domains with illustrative examples. It was assumed that when negative emotions are detected, the robot should react in such a way as to reduce or not escalate them.*

Streszczenie.** Proponujemy wykorzystanie metodologii automatycznego planowania w obecności niepewności do analizy stanu emocjonalnego osoby i możliwych reakcji robota społecznego. Rozważane emocje to: Smutek, Strach, Złość, Obrzydzenie i Pogarda. Rozważane scenariusze obejmują modelowanie niepewności w detekcji emocji. Efektem pracy jest zestaw dwóch domen planistycznych wraz z ilustrującymi je przykładami. Założono, że w przypadku wykrycia negatywnych emocji robot powinien reagować w taki sposób, aby je zmniejszyć lub nie eskalować. **(Reakcja robota społecznego na negatywne emocje jako problem planowania PDDL z uwzględnieniem niepewnej informacji).

Keywords: artificial intelligence planning, sensory planning, social robotics, emotion recognition.
Słowa kluczowe: planowanie w sztucznej inteligencji, planowanie sensoryczne, robotyka społeczna, rozpoznawanie emocji.

Introduction

The problem of automatic planning in artificial intelligence is formulated as a search for the sequence of the agent's actions (the so-called plan), which transforms the agent's initial environment (called the initial state of the planning problem) into a desired goal-oriented situation (eg [1]).

The problem becomes more complicated if the information about the modelled world is not sufficient to establish all the facts necessary to describe the baseline state of the world. We then say that the initial state of the problem is uncertain, but can be represented by a set of possible initial states. The problem resolution plan can take the form of conditionally implemented actions based on new information that appears when you search for the plan. This approach is called contingent planning ([2], [3]).

The idea of application of automated planning formalism in social robotics is not new but is the subject of ongoing research. One of the ways people communicate is through facial expression. The ability to recognize emotions is important in the context of social robots, as it enables the conversation tone to match the mood of the interlocutor. Human-robot interaction should be seamless, the robot should be able to adapt to the current situation and extract as much information as possible based on analysis of the user's face. Recognition of human emotions can be realized by analyzing facial expression, sound or body language. This paper focuses on emotion recognition using facial expression. Seven basic emotions are detected: fear, anger, happiness, sadness, surprise, disgust and neutrality. Analyzing emotional state based on facial expression is a complicated and complex task. Existing datasets are relatively small in scale, so the network must be taught a good representation using a limited number of training samples. The problem to be solved is Creating an efficient emotion detection algorithm that works in real time.

The study [4] contributes with the list of important aspects that must be taken into account while modelling a classical and deterministic PDDL domain for Social Robotics and executing the resulting plan in their highly dynamic and stochastic environments. In work [5] the Authors develop non-contact rehabilitation therapies for patients with physical impairments based on automated planning reasoning, but the deeper analysis of the problem one can find in [22].

The aim of this study was to investigate the possibility of using the methods of searching for a conditional plan to analyze the emotional state of a person and exerting an influence on the diagnosed state. The uncertainty taken into account was related to the emotional state of a person in interaction with the robot. For the needs of the emotional state analysis, a database of characteristic facial expressions was used, the appropriate combination of which was used to define emotions. The research consisted in modifying one of the classic planning fields, taking into account the uncertainty as to the patient's health [6]. The modification consisted in matching activities representing taking medications and performing laboratory tests to activities modelling human emotional states and performing facial expression analyses. PDDL (Planning Domain Definition Language) [7] has been used to describe the field and planning tasks.

PDDL as a representation of conditional planning task

Following [8] it is assumed that action planning Π (called STRIPS planning) consists of four sets $\Pi=\{C, O, I, G\}$:

- C is a finite set of *conditions*,
- O is a finite set of actions, where each action $o \in O$ takes the form $c^+, c^- \rightarrow c_+, c_-$, where:
  - o $c^+ \subseteq C$ are so called *positive preconditions*,
  - o $c^- \subseteq C$ are so called *negative preconditions*,
  - o $c_+ \subseteq C$ are so called *positive postconditions*,
  - o $c_- \subseteq C$ are so called *negative postconditions*,
- $I \subseteq C$ is an *initial state*,
- $G = \{G_+, G_-\}$ is a *goal situation*, where $G_+ \subseteq C$ are positive conditions (i.e. are true) and $G_- \subseteq C$ are negative conditions (i.e. are false).

In purpose of including in the characterization of the current state of the problem the information that some conditions are unknown (suppose that k conditions may be true or false), one might introduce the so-called k-states proposed by [9]. In simple terms ***k-state*** is a pair (S, Σ), where S is the current problem state, and Σ is a set that consists of all possible states. For unknown initial state set Σ consists of all states S, for which:

- condition $c \in C$ is true in the initial state (i.e. $c \in I$),
- condition $c \in C$ is false (i.e. $\neg c \in I$),
- if it is unknown whether condition $c \in C$ is true or false in the initial state then set Σ includes both states for which this condition is true and false.

The initial state I can be potentially any state from states included in set Σ.

Robotic intelligent systems are commonly armed with various types of sensors that are designed to determine various properties of the surrounding robot environment. This and other information can be represented to the degree of truth of the conditions that determine the current state of the problem. This is typically being done by implementing specialized operations referred to as *sensory actions* [9]. Since no formal extension of STRIPS planning to sensory actions exists, a definition of these actions for k uncertain conditions is being proposed below as a dedicated special subset of STRIPS actions.

Definition. For k unknown conditions set of sensory actions O_s is a finite set of actions, where for each sensory action o_s it is needed to introduce two STRIPS sensory actions

$\{ o_s^t, o_s^f \} \in O_s$ that take the form:

- $o_s^t : c^+, c^- \rightarrow c_i$, if condition c_i is true after performing action o_s,
- $o_s^f : c^+, c^- \rightarrow \neg c_i$, if condition c_i is false after performing action o_s,

for i = 1,2…k. It follows that the number of STRIPS sensory actions $|O_s| = 2k$.

The effect of the application of an action to the present state is determined by whether the action is conventional or sensory. The explanation of this result is given below, is on the basis of [2] and is mapped to the STRIPS problem.

For action o, *k-state* is described by a set $\{Result(S,\{o\}), Result(\Sigma,\{o\})\}$, where $Result(S,\{o\})$ is the same like in the case with complete information, e.g.:

(1) $Result(S, \{ \}) = S,$

(2) $Result(S, \{o\}) = (S \cup c_+) \setminus c_-$ if $c^+ \subseteq S \wedge c^- \cap S = \emptyset$; S in opposite case,

(3) $Result(S, \{o_1, o_2,....., o_n \}) = Result(Result(S, \{o_1\}), \{o_2,...., o_n\}),$

(4) $Result(\Sigma,\{o\}) = \{ Result(S',\{o\}) \mid S' \in \Sigma \}.$

For sensory actions o_s, current state S remains the same, whereas the set Σ is reduced to set of states, for which condition $c_i \in S$:

(5) $Result(\Sigma,\{o_s\}) = Result(\Sigma',\{o_s\})$,

where: $\Sigma' = \{S' \in \Sigma \mid (c_i \in S' \leftrightarrow c_i \in S)\}$.

It results that the planning problem with incomplete information on the initial state has a form of five sets of:

(6) $\Pi = \{C, O, O_s , \Sigma, G\}$.

Expression of negative emotions

Emotions are regulatory processes that are triggered when a person comes into contact with stimuli whose meaning is important for the body or personality [10]. There are four types of emotional triggers:

i. Endogenous (arising in the mind) and exogenous (arising in the surrounding world) stimuli.

ii. Physiological correlates, i.e. the activity of the central peripheral nervous system.

iii. Cognitive assessment, i.e. the assessment of events by the person who gives them meaning.

iv. Motivational qualities, i.e. goals and aspirations accompanied by emotions.

Emotions differ from feelings in that they come suddenly and are intense, causing immediate action. Emotional processes are mental activities that relate to reality. Each emotion can be described by characterizing its 3 main components:

• intensity
• sign (influence)
• contents

The intensity of the emotional process depends on how important the stimulus is for the person. The higher its stimulation, i.e. the greater its activation, the greater the mobilization of energy to act, i.e. the stimulus is more intense [10]. The sign of the emotional process is influenced by the direction of the reaction to which the stimulus stimulates the person. There are two types of emotions:

• positive, that is, pleasant
• negative or unpleasant

Emotions vary in quality depending on the factor that causes them and the type of reaction to which they are prompted. These factors make up the content of the emotional process. Negative emotions were selected for the study, indicating how the social robot could react to them in order to reduce them. The most popular division is made by Paul Ekman, who distinguish seven universal facial expressions (anger, contempt, disgust, fear, happiness, sadness and surprise). But, it is worth noting that studies concerning universal facial expression are steel continued and many researchers [11] suggests that people can represent even 16 complex expressions, that may be unified over the globe.

Sadness

Sadness is felt as a result of losing someone important or not achieving a goal. It is accompanied by a bad mood and a feeling of depression. Paul Ekman and Wally Friesen have suggested that sadness has two separate aspects - sadness and anguish [4]. The gesture characteristic of sadness is to raise and draw the eyebrows. Also the upper eyelids are slightly drooping and the lower eyelids are slightly tense. A combination of all the signs of sadness are: The eyebrows are raised and pulled together so that the inner corner is raised, the upper eyelids slightly droop, the corners of the mouth are lowered and the cheeks are raised. The last of these microgests shapes the wrinkles (the so-called nasolabial folds) that run from the nostrils, beyond the corners of the mouth. The muscle responsible for lifting the cheeks also creates these furrows and pushes the skin under the eyes, causing them to narrow.

Fear

Fear is felt when the source of the anticipated threat or danger is known. The inability to identify this source causes anxiety [12]. Fear is a person's reaction to a real, immediate, and physical threat to the physical self. Anxiety arises as a result of a feeling of an undefined threat to oneself and personality [13].

When the tension of the lower eyelids occurs along with the lifting of the upper eyelids, while the rest of the face is expressionless, it is very likely that the person is feeling fear. The eyebrows are pinched and raised, when you add the upper eyelid lift that usually occurs with lower eyelid tension, the scared expression reappears. Fear can also affects with mouth muscles leading to open mouth [14].

Anger

Anger occurs when we destroy our goals. It is aimed mainly at people we love or like, not those we don't like [12]. Anger is associated with aggressive behavior. The lower eyelids are slightly tense and the upper eyelids raised, which gives the effect of glaring eyes with slightly lowered and pulled eyebrows, which proves that anger is inhibited. Also staring intensely can be associated with anger [15].

Disgust

Disgust is caused by objects or situations that are repulsive to us. They can be seen in an infant after putting something bitter in their mouth. According to Paul Rozin, finding something disgusting by a person depends not only on the nature of the object, but also on its origin, social history and what it resembles. Disgust can also be felt towards immoral and socially unacceptable acts. This emotion does not cause major problems for the person experiencing it, but when performing certain jobs, one must undergo devout training [13]. Disgust is signalled by two very different grimaces: the first is the wrinkle of the nose, the second is the upper lip lift.

Contempt

Contempt has a lot to do with disgust, but there are differences that distinguish these emotions. “We only feel contempt for people and their behaviour, not for smells, tastes or tactile sensations. Walking into a dog's poop can be disgusting, but never contempt, the very thought of eating a calf's cerebellum can be disgusting, but never disdainful. However, it is possible to despise people who eat such disgusting things because contempt contains an element of superiority to its object; a lack of respect for people or their behaviour makes you feel better (usually in a moral sense) than them. is demeaning. but you don't have to run away from them right away, which you would do in case of disgust ”[4].

Contempt, although counted as a negative feeling, can be nice to people when they feel it. This feeling can then turn into the embarrassment of realizing that you are experiencing pleasant sensations during the emotion. This applies especially to people who are less confident in their status, who, referring to contempt, try to emphasize their superiority over others [4]. Contempt is the only emotion that expresses itself in a one-sided expression on the face. It is characterized by a tight and slightly raised corner of the mouth.

Automated recognition and reduction of negative emotions as a conditional planning problem

In this section we introduce PDDL domains for automated recognition and reduction of negative emotions by social robots, implemented on ACL (Allegro Common Lisp) platform [16], in which the Sensory Graphplan algorithm is the scheduling algorithm [17] that solves problems. Proposed domains address two problems:

Table 1 Actions with PDDL effects for “emotions basic” domain

Action	Type of action	Effects of action
test_check	with conditional effects	(and (when (sadness) (test_result_1)) (when (tornment) (test_result_2)))
emotion_analysis	sensory	(and (observes (test_result_1)) (observes (test_result_2)))
sadness_therapy	with conditional effects	(and (when (sadness) (not (sadness))) (when (not (sadness)) (depression)))
tornment_therapy	with conditional effects	(and (when (tornment) (not (tornment))) (when (not (tornment)) (depression)))

1. The first domain of planning problem, called “emotions basic”, concerns the task of recognizing and reacting a social robot to two related emotions: sadness and anguish. They are distinguished using the "*test_check*", which determines what score characterizes the emotion, while the sensory action "*emotion_analysis*" indicates the score obtained by the patient. Then, using the "*sadness_therapy*" and "*tornment_therapy*" actions, he is subjected to the appropriate, for his emotional state, treatment. It is assumed that an improperly selected therapy causes the patient's condition to deteriorate, which describes the corresponding conditional effect of the therapy actions. The domain is defined in Table 1 using PDDL formalism, where sets *C* and *O* of planning problem (6) are given as:

(7) *C* = {*sadness, tornment, test_result_1, test_result_2, depression*},

(8) *O* = {*test_check , sadness_therapy, tornment_therapy*},

(9) O_S = { *emotion_analysis* }.

2. The second domain, called “emotions complex”, is an expanded version of the previous one, in which the task of a social robot is to respond to a complex emotionally uncertain initial situation. It features 5 negative emotions, which are analyzed based on facial expressions. The action *face_expression_recognition* conditions on the basis of which facial expressions specific emotions are interpreted, while the action and *eyebrows_recognition* refine this result. The sensory actions *face_observation* and *eyebrows_expression_observation* indicate the expressions that have been noticed in the patient, thanks to them the appropriate therapy is selected. The wrong therapy results in the deterioration of the of the patient's condition. The domain is defined in Table 2. Conditions introduced are interpreted as follow: *cheeks* - lifting the cheeks; *eyelids* - lifting the lower eyelids and tightening the upper eyelids; *mouth_corner* - lifting the corner of the mouth; *eyebrows* - draw your eyebrows towards each other. The domain is defined in Table 2 using PDDL formalism, where sets *C* and *O* of planning problem (6) are given as:

(10) *C* = {*sadness, disgust, anger, fear, contempt, depression, cheeks, eyelids, mouth_corner, eyebrows*},

(11) *O* = {*face_expression_recognition, eyebrows_recognition, therapy*},

(12) O_S = {*face_observation, eyebrows_expression_observation*}.

Table 2 Actions with PDDL effects for “emotions complex” domain

Action	Type of action	Effects of action
face_expression_recognition	with conditional effects	(and (when (or(sadness)(disgust))(cheeks)) (when (or(anger)(fear))(eyelids)) (when (contempt)(mouth_corner)))
face_observation	sensory	(and (observes (cheeks)) (observes (eyelids)) (observes (mouth_corner)))
eyebrows_recognition	with conditional effects	(and (when (or (sadness)(fear)) (eyebrows)))
eyebrows_expression_observation	sensory	(observes (eyebrows))
therapy (?emotion)	with conditional effects	(and (when (?emotion) (not (?emotion))) (when (not (?emotion)) (depression)))

Scenarios for “emotions basic” domain

In the first planning problem, uncertainty applies only to sadness, so the uncertain construct was used to define it. The patient may feel sadness or not feel it (this means that he or she is in a state that does not require treatment). The goal is to bring him to a good emotional state, therefore it is necessary, with the help of action sensory action to diagnose the patient's condition in order to give him the right treatment. Wrong selected therapy results in worsening of the patient's condition.

The uncertainty about the sadness leads to two possible initial states. In the first, the patient does not feel any of the emotional states under study, while in the second he feels sadness. The *emotion_analysis* action determines whether to give the treatment or whether the patient is in world 1, i.e. does not require treatment. The problem is defined in Table 3 in PDDL formalism, i.e. the initial state of the problem and the set *G* from formula (6) are given. Resulting possible worlds (i.e. initial states, the set Σ in formula (6)) and the solution are presented in Table 4.

Table 3 The initial state of the first planning problem and the set G

Initial state of the first problem	**The goal state of the first problem**
(not (test_result_1)) (not (test_result_2)) (not (depression)) (not (tornment)) (uncertain (sadness)))	(and (not (sadness)) (not (tornment)) (not (depression)))

Table 4 Possible worlds and the solution of the first planning problem

Possible world 1	**Possible world 2**	**Conditional plan**
(not (sadness)) (not (tornment)) (not (depression)) (not (test_result_2)) (not (test_result_1))	(sadness) (not (tornment)) (not (depression)) (not (test_result_2)) (not (test_result_1))	1. test_check 2. emotion_analysis 3. sadness_therapy if not in world 1

In the second planning task, the patient may feel sadness, anguish or no feel any of the listed emotions, so uncertainty in the initial state was defined using the *oneof* construct. As in the previous task, the goal is to select the patient with the appropriate therapy to improve his emotional state; referring the patient to the wrong therapy will result in a worsening of his emotional state. The uncertainty about one of three possible emotional states leads to three possible initial states of the planning problem.

The problem is defined in Table 5 in PDDL formalism, i.e. the initial state of the problem and set *G* from formula (6) are given. Possible worlds (i.e. initial states, the set Σ in formula (6)) and the solution are presented in Table 6.

Table 5 The initial state of the first planning problem and the set G

Initial state of the second problem	**The goal state of the second problem**
(not (test_result_1)) (not (test_result_2)) (not (depression)) (oneof (and (sadness) (not (tornment))) (and (not (sadness)) (tornment)) (and (not (sadness)) (not (tornment)))))	(and (not (sadness)) (not (tornment)) (not (depression)))

Table 6 Possible worlds and the solution of the first planning problem

Possible world 1	**Possible world 2**	**Conditional plan**
(not (sadness)) (not (tornment)) (not (depression)) (not (test_result_2)) (not (test_result_1))	(sadness) (not (tornment)) (not (depression)) (not (test_result_2)) (not (test_result_1))	1. test_check 2. emotion_analysis 3. sadness_therapy *if not in world 1*

Scenario for "emotions complex" domain

In the third planning problem, the patient feels one of four negative emotions and it is the source of uncertainty. The problem has also an additional initial property in which the patient feels anger and this fact is true in the initial state. The problem is defined in Table 7 in PDDL formalism, i.e. the initial state of the problem and set *G* from formula (6) are given. Possible worlds (i.e. initial states, the set Σ in formula (6)) and the solution are presented in Table 8.

Table 7 The initial state of the third planning problem and the set G

Initial state of the third problem	**The goal state of the third problem**
(not (cheeks)) (not (eyelids)) (not (mouth_corner)) (not (eyebrows)) (oneof (sadness)(fear)(anger)(disgust)) (not (contempt)) (not (depression)))	(and (not (sadness)) (not (fear)) (not (anger)) (not (disgust)) (not (contempt)) (not (depression)))

Table 8 Possible worlds and the solution of the third planning problem

World 1	**World 2**	**World 3**	**World 4**	**Conditional plan**
(object contempt) (object disgust) (object anger) (object fear) (object sadness) (not (depression)) (not (contempt)) (disgust) (not (sadness)) (not (fear)) (not (anger)) (not (eyebrows)) (not(mouth_corner)) (not (eyelids)) (not (cheeks))	(object contempt) (object disgust) (object anger) (object fear) (object sadness) (not (depression)) (not (contempt)) (not (disgust)) (anger) (not (sadness)) (not (fear)) (not (eyebrows)) (not(mouth_corner)) (not (eyelids)) (not (cheeks))	(object contempt) (object disgust) (object anger) (object fear) (object sadness) (not (depression)) (not (contempt)) (not (disgust)) (not (anger)) (fear) (not (sadness)) (not (eyebrows)) (not(mouth_corner)) (not (eyelids)) (not (cheeks))	(object contempt) (object disgust) (object anger) (object fear) (object sadness) (not (depression)) (not (contempt)) (not (disgust)) (not (anger)) (not (fear)) (sadness) (not (eyebrows)) (not(mouth_corner)) (not (eyelids)) (not (cheeks))	1. eyebrows_recognition *or* face_expression_recognition 2. face_observation *or* eyebrows_expression_observation 3. therapy disgust *if not in worlds* 2 3 4 4. therapy anger *if not in worlds* 1 3 4 5. therapy fear *if not in worlds* 1 2 4 6. therapy sadness *if not in worlds* 1 2 3

It should be noted that for the third conditional plan problem the robot is able to perform some actions in parallel. It is caused by the fact that sets of actions are not *mutually excluded*, i.e. changing the order of applying the action, or apply them simultaneously does not lead to contradiction. In the plan presented in Table 8 actions *eyebrows_recognition* or *face_expression_recognition* can be performed in parallel or in any order. Similar property could be observed for sensory actions *face_observation* and *eyebrows_expression_observation*. The property of executing in parallel some of the decisions that are components of the plan can be used to reduce the execution time of the entire plan, in this case patient interaction (see e.g. [18]).

Discussion and conclusion

The research involved modification of the classical medical planning field, taking into account uncertainty about the patient's state of health. The modification consisted in matching actions representing taking medications and performing laboratory tests to actions modelling human emotional states and conducting psychological tests. The result of the modification is a new field of automatic planning containing the field definition and a set of planning problems.

In the part concerning the simulation research, a number of tests were carried out using the newly created planning domain. Research results indicate the usefulness of classic methods of automatic planning for the analysis of emotional states. It should be noted that the examples considered are very simple and indicate possible future directions of work development. Among them, we can distinguish the development of the field of planning taking into account the more complex emotional states of man and complex forms of reactions or psychological therapies conducted by social robots. There are potential possibilities to integrate classic automatic planning methods with visual facial expression recognition systems.

When building more complex automated planning systems one can be faced with the problem of efficient in time methods for searching the plan that is caused by the usually high computational complexity of planning problems especially in the presence of uncertainty [9]. The combinatorial and efficiency studies for emotion recognition as a planning problems has been studied in [19].

To overcome this difficulty we work for hybrid algorithms based on transformation of planning problems to linear programming. Our results indicate the usefulness of this approach [20] when integrating the planning system with OhBots expressing emotions robots interacting with human [21] within the Social Robots laboratory developed by Department of Automatic Control and Robotics at Silesian University of Technology.

Acknowledgements: *The work of Eryka Probierz was supported in part by the European Union through the European Social Fund as a scholarship under Grant POWR.03.02.00-00-I029, and in part by the Silesian University of Technology (SUT) through a grant: the subsidy for maintaining and developing the research potential in 2023 for young researchers in data collection and analysis. The work of Adam Galuszka was supported by the SUT Grant No. 02/060/BK_22/0030, the subsidy for maintaining and developing the research potential in 2023. The work of Anita Galuszka was supported by the Katowice Business University subsidy for maintaining and developing the research potential in 2023. The calculations were performed with the use of the IT infrastructure of GeCONiI Upper Silesian Centre for Computational Science and Engineering (NCBiR grant no POIG.02.03.01-24-099/13).*

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