Review Paper

"Does cinema form the future of robotics?": a survey on fictional robots in sci-fi movies

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Abstract
Robotics and Artificial Intelligence (AI) have always been among the most popular topics in science fiction (sci-fi) movies. This paper endeavors to review popular movies containing Fictional Robots (FR) to extract the most common characteristics and interesting design ideas of robots portrayed in science fiction. To this end, 134 sci-fi films, including 108 unique FRs, were investigated regarding the robots' different design aspects (e.g., appearance design, interactive design and artificial intelligence, and ethical and social design). Also, in each section of this paper, some characteristics of FRs are compared with real social robots. Since some researches point to the significant role of the cinema in forming the community's expectations, it is very important to consider these characteristics and differences in choosing the future pathway of robotics. As some examples of findings, we have found that unlike the non-metallic skins/covers of real social robots, most FRs are still covered by highly detailed metal components. Moreover, the FR ability of interactions are generally (more than 90%) shown to be similar or even more advanced than normal Human–Human interactions, and this milestone was achieved by ignoring the AI challenges of real HRI. On the other hand, the ethical aspects of movies do inspire us to consider the potential ethical aspects of real robot design. All in all, according to popularity of movies, studying FR could be a step toward more appropriate development of robotics and AI entities to be accepted by general users in the real world.

Highlights:

- We reviewed 134 sci-fi movies containing 108 unique fictional robots regarding different design aspects.
- Fictional Robot (FR) is an artificial entity acting as a result of a fictional technology and playing a role in a movie.
- Investigating fictional robots can shed light on the development of real robotics and AI entities.

Keywords Fictional robots · Science fiction movies · Social robot · Robot design · Artificial intelligence (AI) · Robot ethics

1 Introduction

After watching only a few science fiction (sci-fi) classics, one quickly realizes that robotics and artificial intelligence (AI) have always been a compelling topic in sci-fi movies. As a manifestation of advanced technology, robots play an important role in depicting the future of humans in sci-fi movies. In fictional worlds, Fictional Robots (FR) are usually ideal candidates for unpleasant or dangerous jobs (i.e., servants, soldiers, etc.) due to their inexhaustibility,

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strength, and complete obedience. Moreover, robotic technology has also been used as a tool to grant human's eternal wishes: inviolable comfort and immortality.

Some researchers believe that sci-fi writers are shaping the future of technology by inspiring engineers: Marcus [1] shows some examples of technologies predicted (or inspired) by sci-fi movies; Jordan and Auernheimer [2] searched for references to Star Trek in the ACM Digital Library and found 232 papers until 2017; Some others like Jordan et al. [3] and Russell and Yarosh [4] explored the theoretical aspects of this inspiration process. Alternatively, it is also argued that these movies shape the conception of robots in ordinary people's minds, as the main potential consumers of robots in the future [5]. On the other hand Robotics and the robots' presence among the society shows an accelerating growth [6–10], especially in service positions like education [6, 7], health care [8, 9], sales and marketing [10], etc. Therefore, it is important to analyze fictional robots to better understand the market's needs and to seek inspiration for better designs. While it is no surprise that researchers are interested in studying the fiction and reality relationship, there appears to be a lack of detailed and exhaustive analysis of robotic sci-fi movies in the literature. Researchers have examined this relationship in different ways. Some researchers have used a limited number of movies; i.e., Lorenčík et al. [11] examined 6 sci-fi movies from many aspects such as the technology behind the stories and their real-life applications; others examined movies from a number of limited viewpoints; i.e., Bartneck [12] examined fictional robots mainly to find their attitude and similarity to humans; some other researchers studied the relationship of movies and reality in detail; i.e., Riek et al. [13] performed a trial to find a positive correlation between watching sci-fi movies and the positive attitude toward robots. Also some research groups have tried to use sci-fi materials as a tool to study robotics and AI as a whole; i.e., Clark [14, 15] analyzed the Asimov's laws of robotics for possible real-life situations. Murphy also wrote at least two books [16, 17] and many articles (i.e., [18–21]) to connect sci-fi movies and stories to real-life applications and challenges in robotics and AI.

The silent movie *Metropolis* (1927) was one of the first movies that dealt seriously with robots. Two decades later (in 1950s) Isaac Asimov published his stories which somehow organized the basic foundations of social robots [9]. Since the 1980s, advances in automation have paralleled improvements in the role of robots in cinema. With the boom of AI in the late twentieth century, sci-fi movies have become fascinated with the subject of robotics. In this paper, we try to examine and compare the characteristics of 108 unique fictional robots depicted in 134 of the best sci-fi movies (determined by an IMDb score above 5) through three categories: 1) Appearance design, 2) Interactive design and artificial intelligence, and 3) Ethical and social design. We endeavored to figure out the most common characteristics of fictional robots in the movies as well as the sci-fi movie makers' viewpoint regarding the robots. The situation of real social robots is also compared to the investigated fictional robots in cases where there are fundamental differences between real and fiction. To the best of our knowledge, a general survey on fictional robots or a comprehensive comparison of the orientation of fictional and real social robots has not been reported in the literature.

2 Material and method

In this review study, we examined 134 movies containing at least one fictional robot. Figure 1 presents the number of investigated movies with regard to their year of production and IMDb score. It should be noted that film franchises containing the same robots are considered as only one robot in this paper (i.e., the first produced movie in each series). As it is shown in Fig. 1, while there is an increasing trend in producing such movies over time, 45 movies (~ 34%) were produced in the just the last five years. Also, less than 6% of the selected movies were produced before 1980. Our consideration when selecting these movies was almost always their current popularity. Because we wanted to investigate the general expectations for future robots.

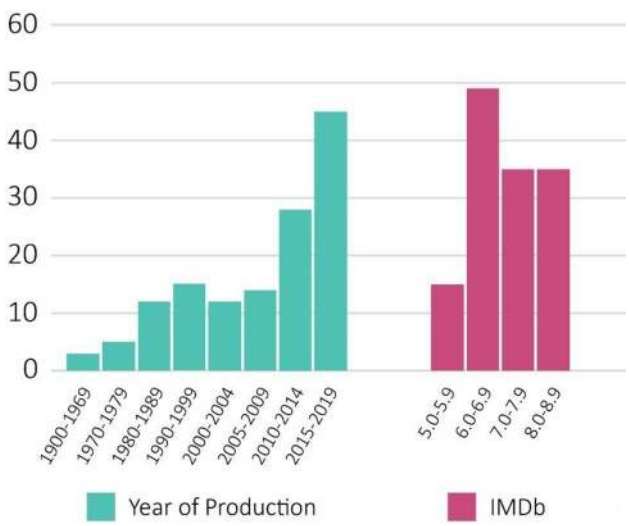

Fig. 1 Chart of the movies' year of production and IMDb score

From these 134 movies, 108 unique fictional robots were extracted and tagged by the authors. Also, it should be mentioned that the main theme of all movies was not necessarily about robotics or AI. Therefore, we have considered any movie in which one or more fictional robots played a role. As an example, the main theme of the *Star Wars series* is not about robotics nor AI, but they include FRs such as "R2-D2", "C3-PO" and "BB-8". As result, in this paper, our classification is based on the number of unique fictional robots, and we ignored the number of movies in which they play.

3 Fictional robots (FR)

First, we propose a definition for a Fictional Robot (FR). In this paper a Fictional Robot is an artificial entity that can sense and act as a result of a (real-world or fictional) technology and played a role in at least one movie. By this definition, aliens such as "E.T." are not consider as FRs because they are not artificial entities. Also, the toy characters in the *Toy Story series* and characters like Pinocchio are not FRs either, because the reason behind their acting and sensing are magical and not technological (not even a fictional technology).

After identifying fictional robots, they were categorized regarding their roles, applications, and design. The fictional robots were studied in three categories: Appearance design, Artificial Intelligence and interactive design, and Ethical and social design, which are described in further detail below.

Let us classify fictional robots into seven applications and use these categories to classify FR throughout the article. Figure 2 presents the number of 108 investigated fictional robots in each category. Some robots had military or security jobs and were tagged as "Soldiers". "Caring and Entertaining robots" are classified as one group, while "Space Assistant robots" are located in another independent group. General-service robots are classified into two groups in this paper depending on if it remains as a service robot until the end of the plot or exits this duty, we refer to them as the "Servant" and "Freedman", respectively. In some other movies, robots are created to be "Immortal Humans", like "David" in *A.I. (2001)*. Finally, the last group includes robots that are "Not Human-Made" independent creatures.

Examples for each of these 7 categories are presented below:

- *Soldier:* "T-1000" in *Terminator 2 (1991)* or "Chappie" in *Chappie (2015)*
- *Caring & Entertainment:* "Baymax" in *Big Hero 6 (2014)* or "Hosts" in *West World (2016)*
- *Space Assistant:* "R2-D2" in *Star Wars (1977)* or "TARS" in *Interstellar (2014)*
- *Servant:* "Samanta" in *Her (2013)* or "Arthur" in *Passengers (2016)*
- *Freedman:* "Andrew" in *Bicentennial Man (1999)* or "Sonny" in *I' Robot (2004)*
- *Immortal Humans:* "Tachikoma" in *Ghost in the Shell (1995)* or "Alita" in *Alita; Battle Angel (2019)*
- *Not Human-Made:* Robots in *Transformers (1984)* or *Robots (2005)*

As shown in Fig. 2, fictional robots usually play the role of a service assistant or soldier (47%). Also, in 15% of the investigated films, robots that served as service assistants at the beginning of the story, but leave their assigned task through the main story of the film (i.e., categorized as the Freedman).

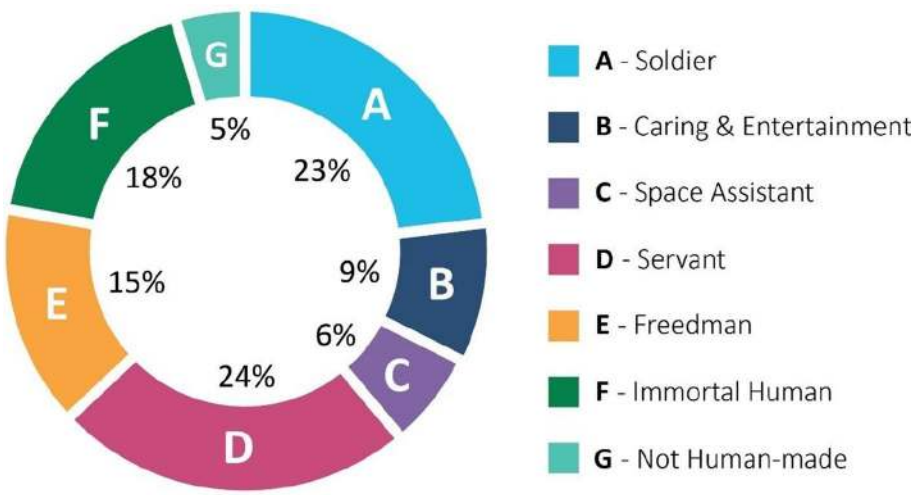

Fig. 2 The percentage of investigated movies in each fictional robots' classification category

3.1 Appearance design

The appearance design of fictional robots was selected as an important factor to be investigated in this paper [24]. In general, the appearance design of fictional robots can be divided into the five main categories below (with some real-life robot examples):

- *Human-like:* Robots that are quite similar to humans in shape and look, such as Sophia, first citizen robot of the world [25].
- *Metallic Humanoid:* Humanoid robots with metallic parts and other obvious machine-like components, such as the Boston Dynamics' Atlas [26].
- *Non-Metallic Humanoid:* Humanoid robots with a non-metallic shell, it should be noted that most real social robots are built in this way, such as the Arash Robot [27].
- *Non-Humanoid:* Animal-like robots and other robots with non-human-like components, such as most currently available social robots, i.e., Jibo [22] or Keepon [28].
- *Non-Unique Body:* Artificial intelligence entities without a single physical body, such as current voice assistants, i.e., Apple SIRI, Microsoft Cortana, etc. [29].

A diagram of the fictional robot's appearance vs. their application is presented in Fig. 3. As can be seen, most common fictional robots are Metallic Humanoid (usually representing Soldiers) and Human-like robots (usually representing Immortal Humans).

In the next section, we look closer at the FR appearance design through five different sub-categories: Material Selection, Detail Visibility, Uncanny Valley, Transformation, and Name/Gender.

3.1.1 Material selection

As shown in Fig. 3, most of the robots are displayed with a humanoid appearance. On the other hand, 85% (63 out of 74) of the humanoid fictional robots are created with metal. Some are displayed with a metallic appearance, and those robots which usually wear natural skins (e.g., "Mechas" in *A.I. (2001)*) show their metallic understructures (at least once). This fact reveals the audience's expectation of seeing robots as metallic beings. In the real world, however, the expansion of rapid prototyping technology and the cost-effectiveness of plastic has given most real social robots a plastic appearance [30–34]. Observing the function of non-metallic fictional robots (as it is shown in Fig. 3) shows that they are often used for care and entertainment purposes. For example, the "Baymax" care robot in the *Big Hero 6 (2014)* has an inflatable vinyl outer shell that, in addition to being flexible, enables hugging function and safe physical contact.

3.1.2 Detail visibility

Examining fictional robots shows that filmmakers are very interested in detailed designs, especially for metal robots. In *Chappie (2015)* and *Robots (2005)*, we can see many details in the robotic character's design. Additionally,

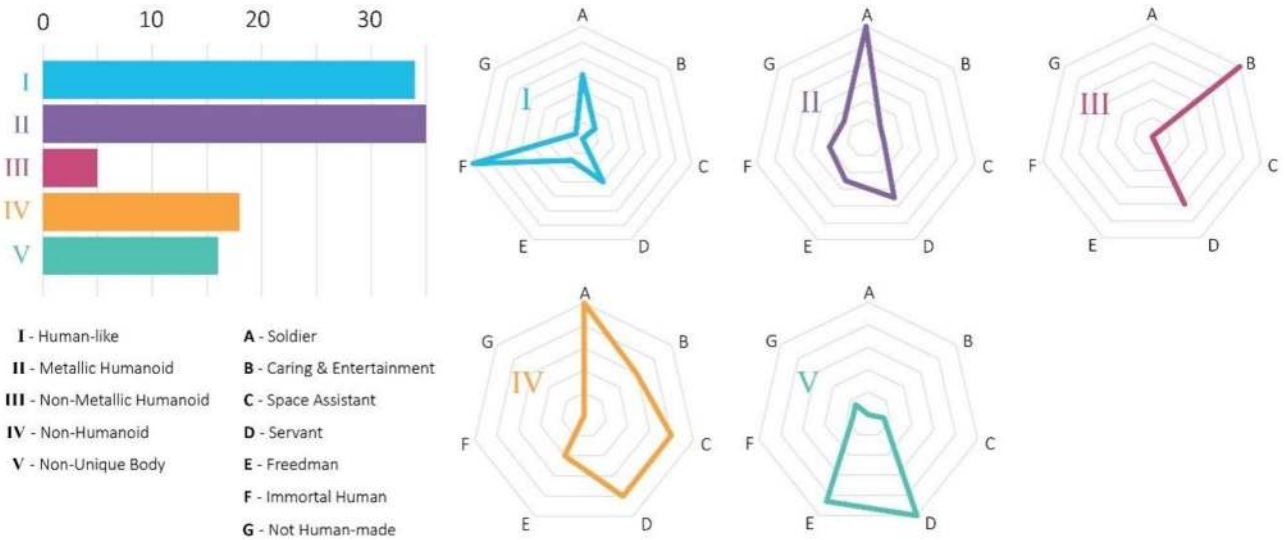

Fig. 3 Rader chart of the studied fictional robots' appearance including the number of robots and the distribution of their roles in each category

almost all fictional humanoid robots have a mechatronic face; however, in the real world, the use of flat displays or static helmets for the robot's face is common practice [34, 35].

3.1.3 Uncanny valley

In the world of cinema, as in the real world, the Uncanny Valley phenomenon [36] is a common challenge in robots' design. Some movies (such as *Uncanny (2015)*) have even chosen this challenge as their main theme. When a humanoid robot's appearance is too close to a human, it causes fear and discomfort in the audience [37]. Hence, fictional humanoid robots' designers often design intentional signs in their robots so they can be easily distinguished from humans. For example, in *Humans (2015–2018)*, this difference is the specific color of the humanoid robots' eyes (synths have shiny green eyes). An android passing as a human is one of the most common puzzles in sci-fi movies, and is often used as a surprise twist in the plot.

3.1.4 Transformation

One attractive feature of a fictional robot is its shape-shifting ability. This feature is so popular that the *Transformers (1984–2019)* franchise is entirely based on this idea. Fictional robots sometimes try to deceive their audience by changing their shape, and sometimes they use this unique feature to do a certain job or cross through specific portals.

3.1.5 Name and gender

As a case of anthropomorphism, the general audience tends to assign a gender to robots for better communication. This gender will be more believable with a wise choice of parameters such as appearance design, name, and tone of voice [37]. Figure 4 shows the gender distribution of the fictional robots of this study.

As can be seen in Fig. 4, approximately half of the fictional robots in the movies we studied are just male (~ 50%). In 12 cases, we see the robot in both genders. Also, in some cases, they are sexless, often non-humanoid robots. We observed that no female robot was portrayed as a space assistant, which may be a sign of an existing male-oriented mentality in the field.

The names chosen for fictional robots are also interesting. Examining the names shows that most fictional robots working in technical environments (in 70% of Soldiers and 100% of Space Assistants examined) have abbreviated names with numbers (such as "C3-PO" and "R2-D2" in *Star Wars (1977)*), while human-like robots often (in 75% of Human-likes examined) have short, easily pronounced human names (such as "Ava" in *Ex Machina (2014)*). This fact is also seen in real-world robot applications [31, 34 and 35].

3.2 Interactive design and artificial intelligence

The robots' intelligence level and their capabilities for human interaction is an always-challenging topic in

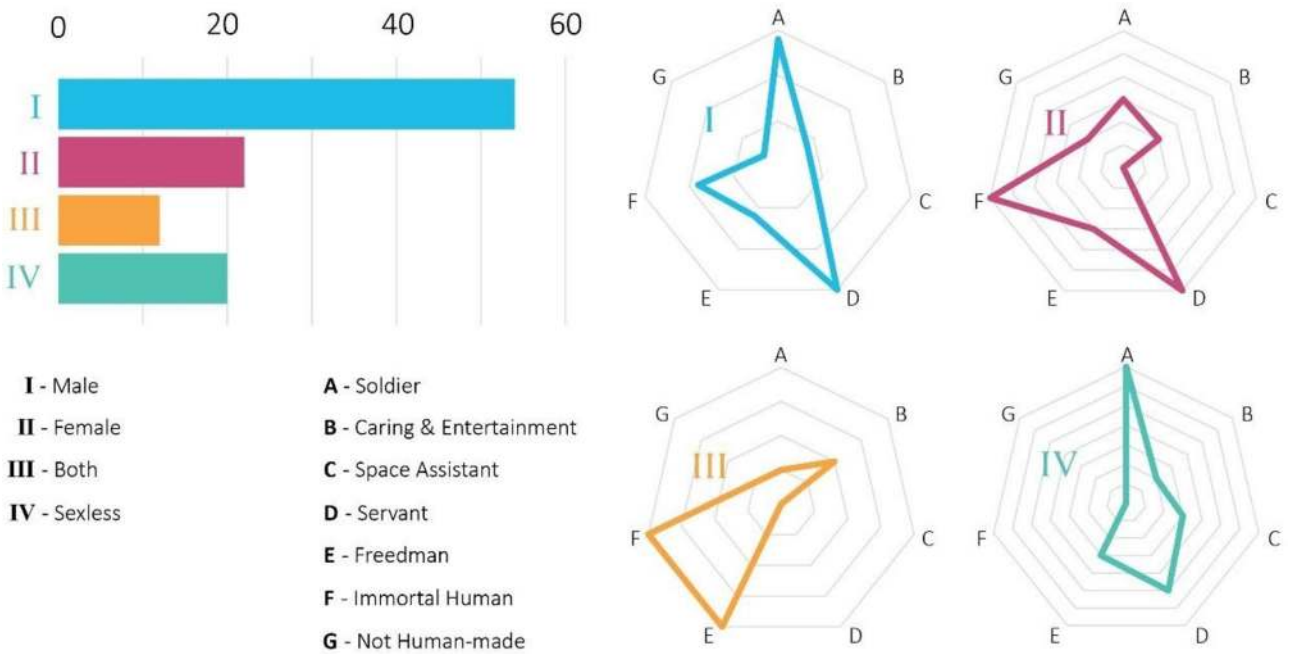

Fig. 4 Rader chart of the fictional robots' gender, including the number of robots as well as the distribution of their roles in each category

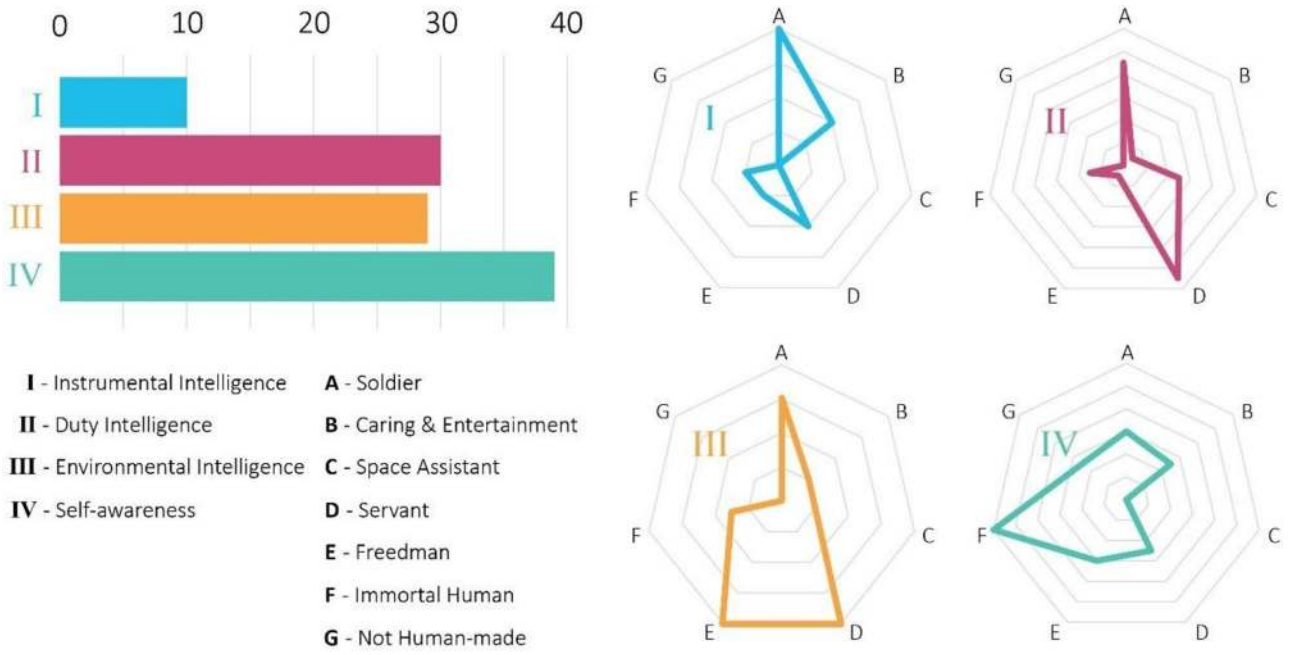

Fig. 5 Radar chart of the robots' artificial intelligence level, including the number of robots as well as the distribution of their roles in each category

fictional robots. We categorized the fictional robots into four levels in terms of artificial intelligence, including instrumental intelligence, duty intelligence, environmental intelligence, and self-awareness. These levels are further defined and described in the following section (Fig. 5).

- *Instrumental Intelligence:* Ability of being manually operated to quickly and accurately control actuators and the inclusion of feedback sensors,
- *Duty Intelligence:* Ability to carry out a mission, taking into account all environmental uncertainties,
- *Environmental Intelligence:* Ability to make decisions based on circumstances and conditions,
- *Self-awareness:* Self-awareness and self-rule.

As shown in Fig. 5, cinematographers are less interested in robots with limited levels of intelligence. This may be because the challenges of human–robot interaction, and therefore an interesting plot for a story, only arise in higher levels of artificial intelligence. In contrast to fiction, most real robots are still limited to instrumental intelligence, and many technical challenges remain in areas such as reliability, accuracy, etc. [34, 38]. In the following section, we studied fictional robots in four subsections referred to as Human-like Interactivity, Superhuman Interactivity, Fictional AI, and Cyborgs.

3.2.1 Human-like interactivity

In order for robots to be able to live among humans, they need to adapt to human living conditions and be able to interact with humans. Fictional robots are no exception to this rule. Hence, one of the obvious characteristics of humanoid robots in most movies is the obvious/definite ability to establish human-like interactions. Of the 74 fictional humanoid robots examined, 68 (i.e., 92%) had the ability to interact with humans at an almost human level. From this we predict that after observing the humanoid appearance and skill of these fictional robots, the general public has come to expect fully human-like interaction ability from future robots. It should be noted that this prediction needs more surveys by the help of questionnaire analysis.

3.2.2 Superhuman interactivity

Many fictional robots can be distinguished from humans because of their advanced sensory capabilities, which we refer to as "superhuman interactivity". Sci-fi writers often try to make their fictional robots superior to humans by giving them special sensory-motor abilities. The most common superhuman interactivity (found in 42 of the observed movies) is advanced image processing, such as

accurate lip-reading ("HAL" in *2001: A Space Odyssey (1968)*) or sophisticated online processing (fast medical scanning of "Baymax" in *Big Hero 6 (2014))*.

3.2.3 Fictional AI

By investigating the characters of artificial intelligence in science fiction films, we can conclude that verbal interaction (i.e., the recognition and synthesis of speech) is considered a necessary ability for an AI entity. Moreover, the entity's ability to speak gives it an identity and personality, and processing the correct speech tone makes it sound commanded and obedient. This is in line with the importance of natural language processing in real-life artificial intelligence reported in [39].

Another human-like ability the audience expects to see from an AI entity is its ability to learn. An advanced fictional AI entity can easily learn new concepts and topics and improve themselves [15]. The subject of robot learning has also received a great deal of research attention in recent years, and several methods have been developed to achieve this ability for robots/machines [40–42].

Moreover, although Humans are limited in terms of information processing and storage, the fictional robot's access to information (using the Internet or even other fictional networks) is almost unlimited, and in some cases, robots are given unlimited control of other digital entities. This feature is more common in bodiless robots. For example, in *I, Robot (2004),* a central AI called "VIKI" with the full control of all other robots is trying to take over the city.

In addition, sci-fi movies rarely try to address real-life engineering challenges, such as the memory and information management challenges found in real-world robots [43]; however, in few movies, such as the *Next Gen (2018)* animation, this issue is observed when the robot is forced to erase his memories due to memory overload.

3.2.4 Cyborgs

Alongside robots, fictional cyborgs also play a role in some sci-fi movies. A cyborg is a human with attached robotic plugins or limbs, or at its most radical level, a human brain controlling a whole robotic body. In our movie database, 27 out of 134 movies (i.e., 12%) addressed cyborgs. Among them, *RoboCop (1987)* and *Alita: Battle Angel (2019)* are widely known examples.

In movies and stories, cyborgs are the best form to address the centuries-old theme of the clash of human nature and machinery. Although connecting a human brain to a robotic body or artificial limbs to a human is an extremely challenging process with our current knowledge and medical limitations, sci-fi writers consider it common practice and portray cyborgs as the perfect examples of this clash of humanity and machinery (i.e., *Ghost in the Shell (1995)*).

3.3 Ethical and social design

Today, with the rapid expansion of artificial intelligence and social robotics [31, 44], the issue of the ethical and social design of robots has become very important [27]. In recent years, several articles have been published by psychologists and sociologists studying the ethical standards and issues in robot design [23]. Similarly, sci-fi writers have shown a great deal of concern for the potential moral challenges of advanced robotics, especially from a human–robot interaction perspective. Also, they may employ fictional robots as metaphorical tools to discuss human ethical challenges. Several of the most important ethical features observed in fictional robots (including Desire for Survival and Evolution, Loyalty, Emotions and Personality, and Robot Abuse) are presented in the following section. Of course, different movies approach these areas with different and diverse viewpoints, i.e. in some movies robots/humans are seeking eternal life while in others they refuse eternal life for different reasons (such as Andrew's rejection of immortal life in *Bicentennial Man (1999)*).

3.3.1 Desire for survival and evolution

One can claim that the first goal of any living creature is to survive. Fictional robots, when they reach the level of environmental intelligence or self-awareness, consider themselves living beings, and this desire to survive also arises in them. The desire to survive leads the robot to begin to experience emotions such as fear, and the desire for evolution leads to the emotion of greed. For example, in *A.I. (2001)* and *Her (2013)*, we see a desire for survival and evolution, respectively. These tendencies can cause war or serious conflict between humans and robots when an artificial intelligence entity, sees the destruction of humans (certain humans or humanity as a whole) as the first step of robots' survival or evolution, i.e., *2001: A Space Odyssey (1968)* and *I, Robot (2004),* respectively.

Although the audience expects a self-aware robot to have a desire for survival and evolution, having creativity and the ability to dream is not expected from a robot. Hence, this occurrence could be surprising in movies like *Chappie (2015)* and *I, Robot (2004)*.

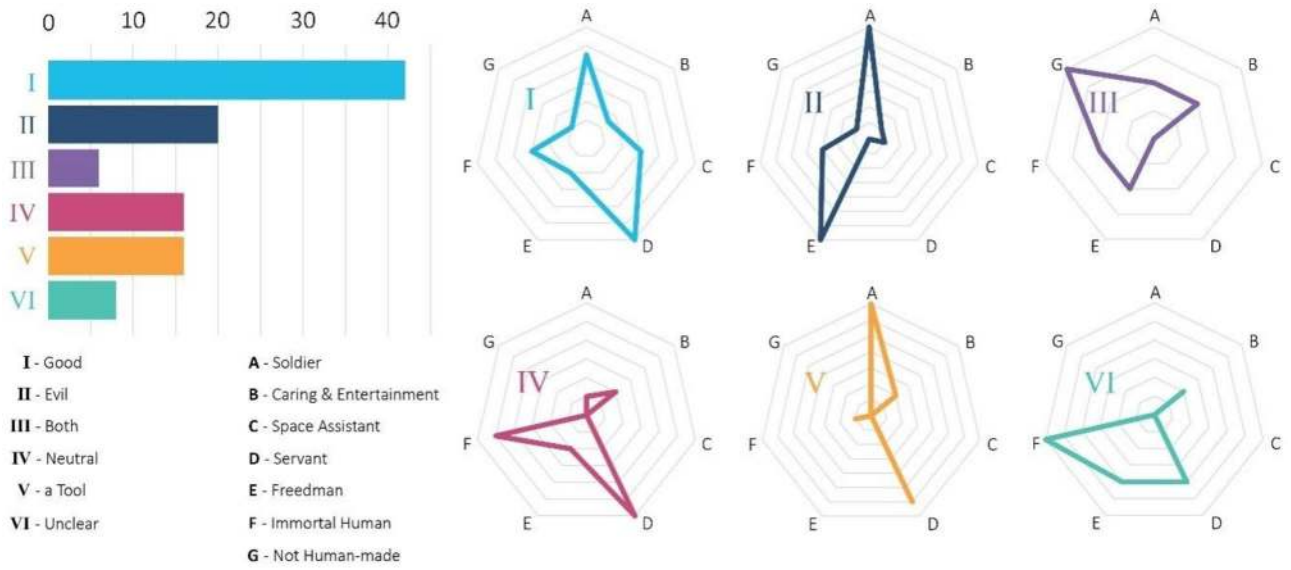

Fig. 6 Radar chart of the robot's overall behaviors, including the number of robots as well as the distribution of their roles in each category

3.3.2 Loyalty

According to our review, 49 out of the 59 fictional robots that play a servant or assistant role showed considerable loyalty to their owners and only ten servant robots violated this loyalty. In some cases, this is due to their limited task intelligence, but sometimes it is due to their ingenuity. For example, the fidelity of the robot in *Robot & Frank (2012)* is due to its conscientiousness, while the fictional robot in *The Iron Giant (1999)* learns to be loyal after befriending humans.

Also, the audience usually expects robots to be obedient, lawful, and insensitive entities. Also, a loyal robot must be value-oriented (i.e., *Chappie (2015)*) and self-sacrificing (i.e., *The Iron Giant (1999)*).

Alternatively, one can categorize fictional robots according to their overall behaviors (e.g., good, evil, both, neutral, and a tool). Figure 6 presents the distribution of the robot's overall behavior in the investigated dataset. It should be noted that we could not classify the robots' behaviors for 8 FRs and use the label "unclear" in for them Fig. 6.

3.3.3 Emotions and personality

If we accept that being able to act and express feelings, through changes in facial expressions, a change in tone of voice, and so on, means a robot has real feelings, we can then claim that the imagination of sci-fi writers has come true. It is also obvious that many human personality traits can be loaded into the robot's artificial intelligence in the form of computer codes [45]. This kind of coding was seen abundantly in the reviewed films. In some movies, such as *Eva (2011)* and *Interstellar (2014)*, we see the ability to customize the robot's emotions and personality parameters, a feature now seen in real social robots such as KIKI [46].

Moreover, in the reviewed movies, there is a strong relationship between having memory and having human-like emotions, including memory retrieval helping robots to have deeper and stronger emotions (i.e., *The Iron Giant* (1999), losing memory being equal to losing personality and emotions (i.e., *Wall-E (2008)*), and injecting human memories into a robot causing it to have the same emotions (i.e., *Astro Boy (2009) and West World (2016–2020)*), etc. These observations are in line with real-life studies on long-term human–robot interactions in which having long-term emotional relations and personality is linked to having a good memory and remembering their shared memories in subsequent encounters [47, 48]. This type of capability is provided in a limited version in the real social robots like Cozmo [49].

An important lesson to learn from these movies when designing a robots' emotion and personality, is that although a robot's feelings and personality is artificial, a person's feelings toward a robot can be quite real (*Her (2013)*). This issue is a main theme in movies which include fictional robots as adopted children or lovers, such as *A.I. (2001)* and *Eva (2011)*.Interestingly, de Graaf [50] also claimed that human–robot interactions are constructed based on the human–human interaction rules.

3.3.4 Robot abuse

Most fictional robots are depicted as man-made creatures, and therefore, are considered inferior to their human creators [51]. As an immediate result of this unique relationship, humans feel a mixture of feelings toward their creations: superiority, love, fear, pity, etc. Some, as a result of negative emotions behave tyrannical, indifferent, and sometimes abusive toward their own creatures [52–54]. Examples of this kind of cruel behavior are depicted in movies such as *A.I. (2001)* and *Humans series (2015–2018)*.

This fact has led some screenwriters to employ these believable but exaggerated examples as metaphors to study issues such as racism, xenophobia, and class divisions in human society. It can be seen in the literature that humans like to have control over robots and they reject dominant behavior of robots [55, 56]. This phenomenon can be seen in movies such as *I am Mother (2019)* or *Tau (2018)*. Therefore, we see a common theme of robot abuse and robophobia in sci-fi literature and movies (which may result in a growth of these negative feelings among their audience). Just as in human history, one observes rebellion, conspiracy, and open war in response to this discrimination as some self-conscious robots try to overcome their creators by seeking freedom, independence, and equal rights. The *West World series (2016–2020)* is one of the most recent examples of this theme.

4 Discussion

After discussing fictional robots from three perspectives: appearance design, interactive design and artificial intelligence, and ethical and social design, it is necessary to draw some general conclusions from the topic. We hope that these issues and all the issues raised so far in this article will be a step toward better development of robotics and artificial intelligence systems in the real world.

4.1 Thirst for power

Man has always sought to create tools for perfection and immortality, and the robot is another one of these. As we can see in movies such as *Iron Man (2008)* or *RoboCop (1987)*, there is an assumption that robotic technology will be able to turn ordinary or even disabled persons into superheroes with superhuman powers. Conversely, some movies often warn people of their excessive desire for power, which can sometimes backfire and destroy already achieved goals.

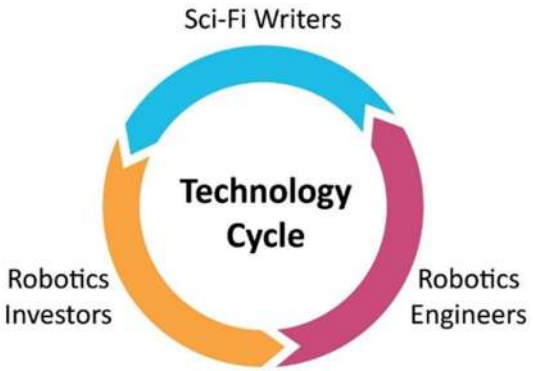

Fig. 7 Technology cycle chart

4.2 Fiction vs. reality

Although fictional robots are "built" on scientific foundations/principles, some capabilities (like great ability in natural language processing) found in a fictional robot created half a century ago are still unattainable in today's real robots. Nevertheless, it is an assumption that fictional robots have inspired the development of technology and the creation of real robots, especially the social robots. As evidence to this claim, we can compare the sound of the R2-D2 robot vs. the Cozmo robot [49], the name and function of the Weebo robot vs. the Jibo robot [22], and the prototype toys of the BB-8 [57] and DIY implementations of R2-D2 [58].

4.3 Technology cycle

The increasing number of fictional robots in recent years shows the great interest of screenwriters and audiences in this technology. As sci-fi writers shape the audience's expectations of the robot [5], they can inspire robotics policymakers and investors, who turn to engineers to bring these fantasies closer to reality. As technology takes another step further, this again inspires writers to find/create new ideas for their stories and screenplays. Therefore, fictional robots play an important role in the development of robotic technology by creating a self-perpetuating technology cycle, Fig. 7.

As an example, during a visit to Carnegie Mellon University's Robotics Laboratory, Don Hall was inspired to create Baymax (The robot in *Big Hero 6 (2014)*). After making the film, Dr. Christopher G. Atkeson, a professor at that robotics lab, decided to make a real Baymax robot and defined a new field of projects called inflatable robotics. "It (*Big Hero 6 (2014)*) is a tremendous win for soft robotics," says Dr. Atkeson [59].

5 Conclusion

Movies containing fictional robots are among the most popular films in today's cinema. In this article, we reviewed 134 well-known sci-fi movies containing 108 unique fictional robots and categorized the characteristics and most common points of the robots based on different aspects of robot design. It was observed that the preferred material for fabricating fictional robots are metals with lots of detail components contrary to the commonly used plastic materials used in real social robots' design. In addition, we indicated that unlike the existing challenge to empower AI robots to behave naturally in real HRI, fictional robots are usually able to interact with humans in an advanced, almost human-like way. We believe that the robotics' community can be inspired by the ethical challenges portrayed in sci-fi films to consider ethical aspects when designing real social robots. Investigating fictional robots can shed light on the development of real robotics and AI entities, even though an enormous gap exists between the fictional and real robots' design and capabilities.

The main limitation of the current study is in the movie selection stage, nearly all of the movies studied in this paper were in English (with few exceptions) and most were produced in the USA and Western Europe. Therefore, we have missed the opportunity to study Non-Western perspectives toward robots and AI in society. In particular, the absence of Japanese sci-fi anime, as a resource full of different aspects of technologies, is a huge drawback. Another limitation of this paper was restricting the study to movies. Extending the domain of study to sci-fi literature will lead to a more diverse and rich study with a greatly extended time frame.

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Author contributions All authors contributed equally to the manuscript.

Declarations

Conflict of interest All authors Ehsan Saffari, Seyed Ramezan Hosseini, Alireza Taheri, and Ali Meghdari declare that they have no conflict of interest.

Appendix

See Table 1

Table 1 List of the Investigated Fictional Robots including the movie's name they present and the year of first presence

	FR Name	Movie Name	Year		FR Name	Movie Name	Year
1	Maria	Metropolis	1927	55	David	Prometheus	2012
2	Robby	Forbidden Planet	1956	56	VGC-60L	Robot and Frank	2012
3	HAL	2001: A Space Odyssey	1968	57	Soldiers	Total Recall	2012
4	Hosts	West World	1973	58	Dorian (DRN)	Almost Human	2013
5	Wives	The Stepford Wives	1975	59	MX-43	Almost Human	2013
6	Proteus IV	Demon Seed	1977	60	Ash	Black Mirror: Be Right Back	2013
7	C-3PO	Star Wars	1977	61	Soldiers	Elysium	2013
8	R2-D2	Star Wars	1977	62	Samantha	Her	2013
9	Ash	Alien	1979	63	Kelex, Kelor	Man of Steel	2013
10	Replicates	Blade Runner	1982	64	Tet	Oblivion	2013
11	Gadget	Inspector Gadget	1983	65	Jaegers	Pacific Rim	2013
12	Edgar	Electric Dreams	1984	66	Ava (Machine)	The Machine	2013
13	T-800	The Terminator	1984	67	Pilgrims	Automata	2014
14	Transformers	Transformers	1984	68	Baymax	Big Hero 6	2014
15	Daryl	D.A.R.Y.L	1985	69	Ava	Ex Machina	2014
16	Johnny 5	Short Circuit	1986	70	TARS, CASE, PLEX, KIPP	Interstellar	2014
17	RoboCop	RoboCop	1987	71	Soldiers	RoboCop	2014
18	–-	Hardware	1990	72	–-	The Nostalgist	2014
19	Taxi Driver	Total Recall	1990	73	Dr. Will Caster	Transcendence	2014
20	T-1000	Terminator 2: Judgment Day	1991	74	F.R.I.D.A.Y	Avengers: Age of Ultron	2015
21	The Dinosaur	Redhat and Cousin	1994	75	Chappie	Chappie	2015
22	Tachikoma	Ghost in the Shell	1995	76	Moose	Chappie	2015
23	Data	Star Trek: First Contact	1996	77	Synth	Humans	2015
24	Weebo	Flubber	1997	78	BB-8	Star Wars: The Force Awakens	2015
25	NDR-114	Bicentennial Man	1999	79	T-3000	Terminator: Genisys	2015
26	Bender Bending Rodríguez	Futurama	1999	80	Athena	Tomorrowland	2015
27	The Iron Giant	The Iron Giant	1999	81	–-	Uncanny	2015
28	Sentinel	The Matrix	1999	82	Amelia	Amelia 2.0	2016
29	David	AI	2001	83	ADIs; Robotic Bees	Black Mirror: Hated in the Nation	2016
30	Mechas	AI	2001	84	Howard	Infinity Chamber	2016
31	Teddy	AI	2001	85	S.A.R	Kill Command	2016
32	Red Queen	Resident Evil	2002	86	Arthur	Passengers	2016
33	B.E.N	Treasure Planet	2002	87	K-2SO	Rogue One: A Star Wars Story	2016
34	T-X	Terminator: Rise of the Machines	2003	88	Hosts	West World	2016
35	Briareos	Appleseed	2004	89	Robotic Dogs	Black Mirror: Metalhead	2017
36	Sonny	I, Robot	2004	90	Karen; Spider Man Cloth	Spider-Man: Homecoming	2017
37	VIKI	I, Robot	2004	91	The Dog	A.X.L	2018
38	Dr. Otto Octavius	Spider-Man 2	2004	92	Synths	Extinction	2018
39	Robots	Robots	2005	93	Gen 6	Next Gen	2018
40	Marvin	The Hitchhiker's Guide to the Galaxy	2005	94	Project 77	Next Gen	2018
41	ARIIA	Eagle Eye	2008	95	Replicas	Replicas	2018
42	Iron Man	Iron Man	2008	96	Tau	Tau	2018
43	JARVIS	Iron Man	2008	97	STEM	Upgrade	2018
44	Gerty	Moon	2008	98	Synths	Zoe	2018
45	Astro Boy	Astro Boy	2009	99	Alita	Alita; Battle Angel	2019

Table 1 (continued)

	FR Name	Movie Name	Year		FR Name	Movie Name	Year
46	Surrogates	Surrogates	2009	100	Ashley Too	Black Mirror: Rachel, Jack and Ashley Too	2019
47	Skynet (T-5000)	Terminator: Salvation	2009	101	Soldiers	Code 8	2019
48	Eve	Wall.E	2009	102	The Mother	I am Mother	2019
49	Wall.E	Wall.E	2009	103	–-	Love, Death & Robots: Blindspot	2019
50	Eva	Eva	2011	104	Yan	Love, Death & Robots: Good Hunting	2019
51	Gris; the Cat	Eva	2011	105	Agriculture Machines	Love, Death & Robots: Suits	2019
52	Max	Eva	2011	106	K-VRC, XBOT 4000, Triangular bot	Love, Death & Robots: Three Robots	2019
53	Prototype 519 (SI-9)	Eva	2011	107	Zima Blue	Love, Death & Robots: Zima Blue	2019
54	Atom	Real Steel	2011	108	Rev-9	Terminator: Dark Fate	2019

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