Smart City Concept Based on Cyber-Physical Social Systems with Hierarchical Ethical Agents Approach

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Abstract. A smart city is considered a sustainable city that manages needed resources and makes autonomous decisions to improve the quality of life of its citizens. On the other hand, Cyber-Physical Systems (CPS) have been implemented as isolated systems inside the city. For instance, the traffic lights, autonomous navigation for cars, and so on. Instead, consider a smart city with an integrated CPS for independent blocks that can be interconnected in a central unit. However, when a CPS makes decisions about the integration of ethical concepts based on human perception, social space must be added, and so a CPS must be transformed into a Cyber-Physical Social System (CPSS). Furthermore, a new type of social interaction between all the elements in a CPSS within a smart city presents human behavioral challenges such as virtual-morality. This paper first proposes an Artificial Moral Agent with machine learning algorithms to regulate the interaction within the CPSS, adding itself to all the subsystems' communication. Additionally, a moral agent structure is proposed with a morality filter as its fundamental component.

Keywords: Cyber-physical systems · CPSS · Social feature · Smart City · Moral agent · AI

1 Introduction

The idea of a "smarter" city to face different problems of urban areas by using technologies to create better life conditions has been around for many years [1]. As [2] shows in an extensive review, the chronological definitions of cities that link technological informational transformations with economic, political, and socio-cultural changes were often referred to as: digital city, wired city, green city, among others. The digital cities concept stands out at the beginning, as the internet started to develop, and it is based on the Information and Communication Technologies (ICT) where people and services are joined and shared to make a smarter community. However, the role of citizens was not prioritized.

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The smart city concept later appeared with the objective to improve the quality of urban life, but it does give the citizens the key role they deserve. Moreover, as ICT is also a prominent part, the digital city is becoming a subset of the smart city. But given the purpose of a smart city is often too large, many frameworks have been proposed to gather all the elements and the relationships between them. Unfortunately, as this concept may include many fields, it has been difficult to develop a straightforward definition.

Therefore, for the purpose of this work, a smart city refers to the management of the relationship between humans (citizens), natural resources, energy, mobility, and buildings to upgrade the quality of life by using the information and communication technologies for optimization.

As it is almost impossible to create a smart city from the ground up, it is easier to propose digital elements applied over the existing infrastructure for citizens to interact and promote social factors. Hence, artificial intelligence (AI) has been applied to many different areas within a smart city, using special agents that can perceive the environment through sensors and act upon that environment through actuators [3]. Some areas of implementation have been:

- Education
- Public spaces
- Smart economy
- Mobility, transport, and logistics
- Energy and smart buildings
- Public safety
- Environment and natural resources
- Health and assistance

In the smart city scenario, some agent-based solutions have been proposed, from evacuation models [4] and emergency responses [5] to driver's decisions on traffic situations [6] and coordination of traffic lights [7].

But the incorporation of AI systems may bring some risks, either because the AI is used to directly cause harm or because somehow the AI becomes unintentionally negative. Eitel-Porter [8] proposes three categories in which the AI risks in a corporation could be organized and tackled:

1. Compliance and governance. Refers to the risk of breaching regulations. The AI could be biased unintentionally during development.
2. Brand damage. Refers to the risk of breaching social norms. The AI could learn bad behavior that could damage the reputation of what it represents.
3. Third-party transparency. Refers to the risk that anybody could generate an AI as a "black box" tool in which the management would not know how it works.

Although these risks are mentioned within a corporation, it is easy to extrapolate the same to a smart city scenario.

On the other hand, AI integration in automation of complex systems has recently made much progress in CPS. These systems integrate computing, communication, and storage capabilities to monitor and control physical processes as is shown in Fig. 1. The CPS focuses on the intersection of the physical and cyber world. This type of system has been demonstrated to provide advantages in sensing, communicating, and processing information locally and globally. However, the interaction with humans is not one of the main strong points of this type of system.

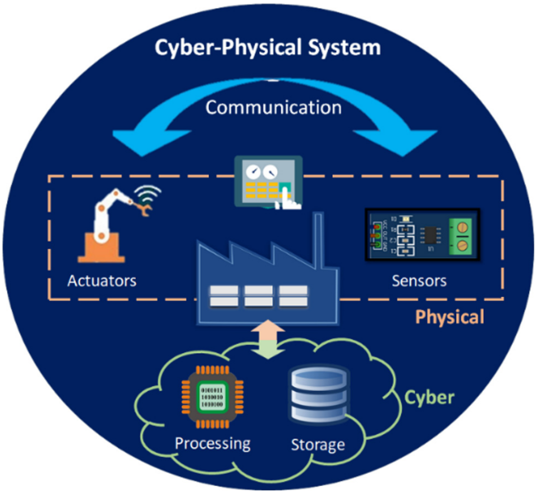

Fig. 1. Cyber-physical system diagram

These kinds of systems manage a large amount of information that is often found in the cloud, as the objective is to represent processes of the physical world by collecting, processing, and managing information [9].

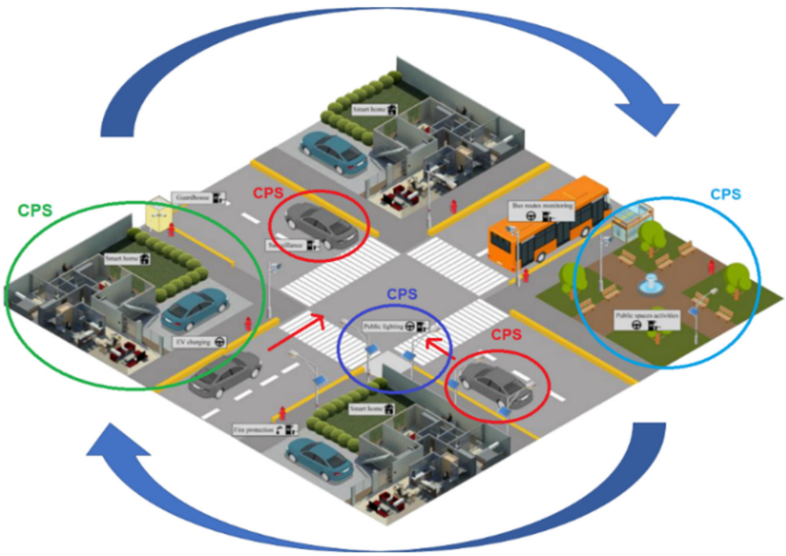

Fig. 2. Set of CPS inside a smart city

Many CPS can be combined in the same environment. If a set of CPS are used under a city environment, this set can resemble some definitions of a smart city. Figure 2 shows an implementation of a smart city with many CPS: an autonomous vehicle driving around the city, the automated traffic lights system, resources control in public spaces, energy consumption in smart buildings, among others.

But as mentioned before, the interaction with humans is not one of the main features of CPS. Although, for example, in autonomous vehicles [10] humans are involved, the true social behavior is not modeled as part of the solution. Therefore, a social component has been added to CPS to enable smart interaction between cyber, physical, and social spaces generating the Cyber-Physical Social Systems concept (CPSS) [11, 12] to meet people's social interaction demands and react to the physical world.

Hence, the human's role in CPSS now becomes fundamental as the social activities impact the smart city environment. Moreover, some social features help to better know the citizens, communities, and cities based on social terms [13–15].

Thus, new challenges regarding the added social space are identified [16]:

- *Device management.* Internet of Things (IoT) technologies and smart devices available today offer a wide range of applications that provide solutions to different CPSS problems. But as these devices lack a unified communication protocol or even a common framework, they require a lot of work to manage. Therefore, an interoperability model in which all the devices can communicate and share information should be developed for enabling CPSS. Besides, the information that is transmitted between devices and users has to be regulated according to ethical considerations.
- *Context-awareness.* Any information used to infer a specific situation of an agent is called a context. Therefore, context-awareness uses that information to provide tailored experiences. In the CPSS environment, the challenge becomes using different types of sensors to obtain data for inferring a context. Due to the high-volume of data, often machine learning algorithms are applied with knowledge-based approaches or even probabilistic approaches. For example, in [17–19], different user types are analyzed using artificial neural networks (ANNs) and fuzzy systems to understand user preferences for tailoring a service.
- *Social computing.* Social computing refers to the use of ICT that considers social context, where CPSS is the infrastructure that enables it. In this way, traditional context awareness moves toward socially aware computing in which the social interaction can be sensed by collecting information from large groups of people [16]. Applications include traffic congestion detection, pollution monitoring, and prediction of diseases. For this new social computing paradigm to improve the design of CPSS, alternative technologies must be considered.
- *Human-Machine Interfaces (HMIs).* Human-machine interfaces are interfaces in which a user can interact between the social, cyber, and physical spaces; a basic need of a CPSS. The interaction, therefore, should be user friendly and be able to adapt or change depending on user behavioral analysis. An example of a tailored HMI is proposed in [20] within a gamification structure that provides feedback and adjusts itself based on the user's profile and behavior to teach, motivate, and engage the end-user to perform specific goals.

- *User behavior-based proactive service.* The goal of this service is to predict human action's intention by understanding human behavior and its characteristics. This is challenging given the sheer variety of users [17].

As human involvement increases in the automation of a smart city under the definition of a CPSS, the systems must consider a new communication channel created between the added social space with moral principles. These moral principles have not been given enough attention as they are often viewed as a negligible side effect of new technologies. Therefore, not only must the moral misconducts of humans interacting with a system be regulated, but the system itself, as decisions involving humans can now be made.

One important concern is in regard to the use of data. As CPSS increases the availability of data, the possibilities of misuse also grow. For example, utility providers may use data to monitor and control appliances in private buildings to redistribute the resources as they better see fit [21]. Further, every technology such as cameras, sensors, devices for human interaction, etc., that collect data, can be subject to biased use that can compromise citizens' privacy.

Another common example of moral dilemma in autonomous machines is in emergency situations like whether a transportation vehicle choose who or what to crash into when it was unavoidable, or, in the case of victims of disasters, who to assist first and based on what criteria [22]. Table 1 shows other examples in relation to smart cities and their moral challenge.

Table 1. Examples of moral challenges

Application	Challenge
Autonomous transportation [23]	Who can get access to the service and how? Data sharing
Occupancy counting and tracking [24]	Using cameras for collecting private data may lead to discriminatory actions or misuse of information
Utilities monitoring systems [25]	Favoring certain people over others: economic status, age, behavior, etc.
Crime prediction [26]	Biased AI; algorithms may tend toward specific demographics
Elderly care [27]	How obtrusive should a system be? Some moral challenges are autonomy, privacy, and physical health

Moreover, the implementation of moral principles in any system is not a trivial task because there is not a global definition of rules or guidelines. Whether it is a philosophical approach, Kantianism and utilitarianism [28]; or an approach of moral theories like moral generalism and moral particularism [29]; or basic rules as Asimov's laws [30]; or even basic principles as fairness, accountability, transparency, explainability, and privacy [8], a common ground must be found where the artificial morality can be implemented.

Hence, this paper proposes an artificial moral agent structure with hierarchical control that can implement some moral guidelines based on a hybrid approach of bottom-up and top-down for artificial intelligence.

2 Proposal

A new type of social device is mentioned in [15] that uses actual technologies to develop a sensing, smart, and sustainable product to communicate between consumer-products and product-products. This proposal goes beyond that model and designs the environment necessary to understand citizens according to their social needs and moral guidelines inside a smart city. Suppose a CPS only dealt with technical data using sensors to monitor, validate, and manage a city. In that case, the city could not achieve the expected result for the citizens because the smartness, in smart city, has become an end in itself, but the needs of the citizens were not realistically tackled. What is needed is a people-centric approach where the CPS must be re-designed into a CPSS system to integrate social capability [31]. Therefore, the CPS should use special sensors to detect social activities and behavior in humans.

Wearables have been gaining popularity as their designs have improved, but also, the increase in functionality for users has made them more appealing. These devices are an example of social sensors used in projects ranging from health [32], to energy [33], to activities [34], and so on.

Developing artificial morality becomes urgent as computers are being designed to perform with greater autonomy [35]. As [36] presented, there have been implementations of AI used in societal environments that show partial and discriminatory responses. Therefore, a computer system should evaluate if its action is morally appropriate in a smart city environment. Such a system should be designed and built by a diverse and inclusive group of people. This is key for avoiding biases and discriminatory behavior against a particular part of the population.

Some approaches were proposed by [35, 37] for designing artificial moral agents (AMA). However, those approaches are not complete since they do not consider the following.

2.1 Top-Down Strategy

This task consists of transforming moral principles and theories into guidelines for morally appropriate actions. With current machine learning algorithms, this approach could be implemented on a computer system. Although, as Tolan [38] shows, biased training data makes predictive performance unreliable. Therefore, an exhaustive search for complete databases must be made to achieve better results. The fundamental example of this kind of strategy is Asimov's laws of robotics [30].

2.2 Bottom-Up Strategy

This task is meant to provide environments in which appropriate behavior is rewarded, i.e., learning through experience. Some machine learning algorithms can handle these kinds of tasks. Still, the risk is that the system does not necessarily learn a morally appropriate action, but an action that may be common in a determined society.

A hybrid strategy implementation of AMA is proposed in Fig. 3. The top-down strategy refers to explicit moral principles, guidelines and rules that are implemented on an agent and the bottom-up strategy looks for implicit values found in the behavior.

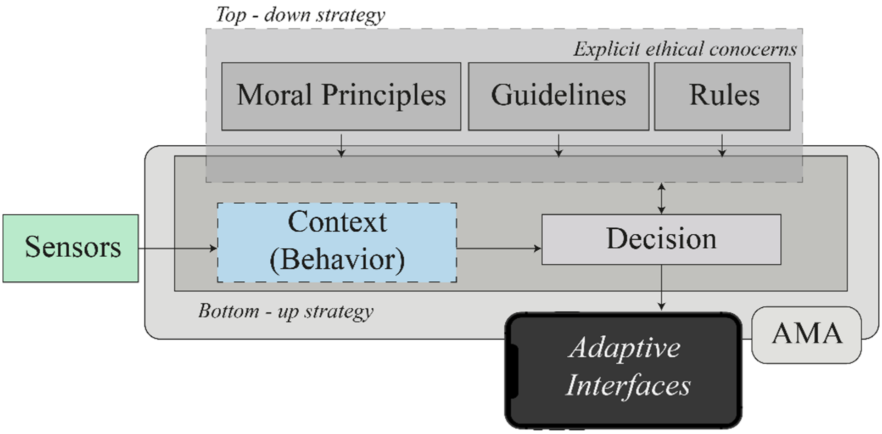

Fig. 3. Top-down strategy and bottom-up strategy involved for designing Artificial Moral Agents (AMA).

Therefore, both strategies merge within the AMA to present the best set of decisions to an adaptive interface. The AMA makes its decision based on the context of the environment and the explicit ethical concerns programmed. The context is deduced by the information gathered from the sensors in the CPSS.

Figure 4 depicts the first part of the proposal where the physical worlds' inputs rely on adaptive, dynamic interfaces that receive and send stimuli to citizens. The citizens actively interact with the interface to obtain information from the physical environment as part of the larger social cyber-physical system. In turn, knowledge from citizens is utilized in the form of social information.

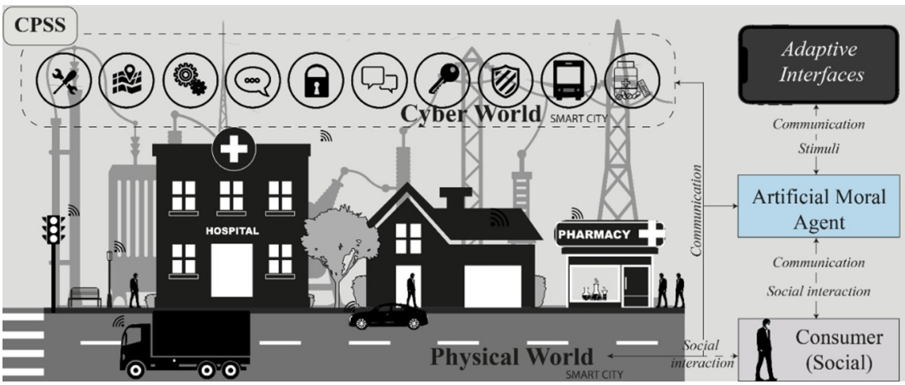

Fig. 4. Moral agent supervising the communication within CPS architecture and the social features.

The CPS becomes a CPSS that can socially interact between them and with citizens using social interfaces. As a result, the CPSS can be defined as a set of social systems that integrate the virtual and physical world in social environments with conventional

CPS information. Still, the priority of CPSS is to improve the communication with humans drastically, and to understand the needs and expectations of citizens for providing social and technical solutions that are accepted by all agents within the smart city. Figure 5 shows how all communication channels between each CPSS space should go through the agent. The term social interface refers to sensing, modeling, managing, and interoperating social factors.

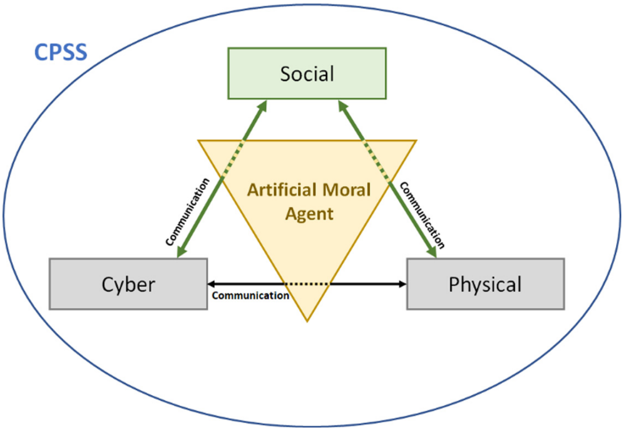

Fig. 5. Moral agent proposed for regulating communication.

Figure 6 shows the second part of the proposal: the moral agent internal structure in which:

$$AMA = \{C_{DS}, P_{DS}, S_{DS}, P_I, M_F, C_{DA}, P_{DA}, S_{DA}\} \quad (1)$$

The inputs $\mathbf{C_{DS}}$, $\mathbf{P_{DS}}$, and $\mathbf{S_{DS}}$, refer to Cyber, Physical, and Social sensorial devices that read environmental data. This part of the structure provides the context information to the agent by merging all the data to better understand its environment.

Then the information is passed to the processing $\mathbf{P_I}$ where social computing takes place. This is possible by using inference algorithms making the core of the AI. The algorithm then gives a set of actions as a result.

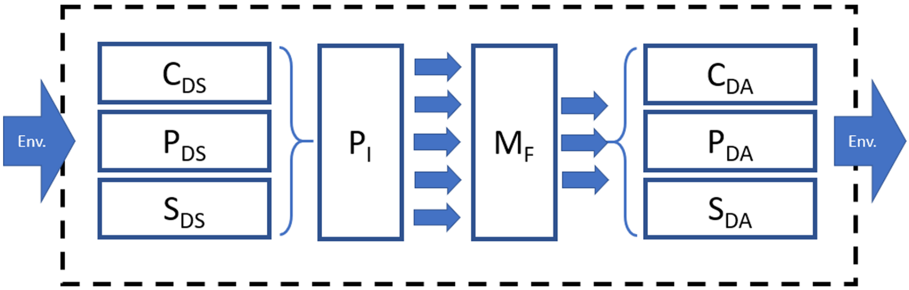

Fig. 6. Moral agent structure

All those possible actions are then passed to the morality filter $\mathbf{M_F}$ in which moral guidelines are applied to filter the most suitable action. This process ensures that the action will include some level of moral principles.

Finally, the $\mathbf{C_{DA}}$, $\mathbf{P_{DA}}$, and $\mathbf{S_{DA}}$ refer to the Cyber, Physical, and Social actuating devices that execute the action upon the environment. The execution of the action may be autonomous, or it may depend on the interaction of a human. In the case when the interaction of a human is needed, an HMI is implemented.

The AMA is added to the CPSS model to evaluate each action, whether morally appropriate, between any of the spaces. The morality part $\mathbf{M_F}$ of the agent may be implemented as an Adaptive Neural Network Fuzzy Inference System (ANFIS) in which a hybrid of both strategies proposed in [35] is implemented. For the top-down strategy part, the fuzzy system can integrate different levels of moral principles or theories that may be appropriate for a specific type of society; in this regard, Floridi [39] states that the Association of Computing Machinery Code of Ethics may be adapted for AMAs. On the other hand, the bottom-up strategy may be implemented on an ANN to let it learn somehow as humans do, by trial and error.

2.3 Artificial Intelligence Ethics

Giving a digital system, like a computer, a robot, or any other agent, the ability to engage in a human-like way of thinking may be considered an implementation of artificial intelligence. However, a precise definition is still a work in progress because even the word intelligence is up for discussion. Artificial intelligence has recently focused on imitating intelligent human behavior; and hence, there is a need to apply ethical guidelines [40].

To make responsible AI is primarily about human responsibility for developing intelligent systems and fundamental human principles and values. Therefore, some considerations have been proposed [41]:

- Ethics by design: integrating algorithms of ethical reasoning that can rule the behavior of AI.
- Ethics in design: analyzing and evaluating ethical implications of AI with engineering methods.
- Ethics for design: ensuring ethical behavior of the developers of AI systems and their users through standards, codes of conduct, among others.

AI ethics considers technological transformation to impact individuals. Europe proposed three ethical principles for a human-centric approach to AI [42]:

- No harm principle: AI algorithms promote inclusion and avoid manipulation and negative profiling to protect more vulnerable groups, like the elderly, children, and immigrants.
- Justice principle: AI developers and implementers must maintain unbiased freedom for all individuals and minority groups.
- Explicability principle: AI systems must be auditable and comprehensible by all types of individuals, either experts or non-experts.

Finally, AI experts should consider inclusion, diversity, and equity topics to augment humanities and social sciences as part of curricular training [43, 44].

Table 2. Moral agent improvement on CPS and CPSS: a comparison.

Smart city subsystem	CPS	CPSS	AMA
Energy	Implementation of smart grid technologies, control energy consumption, optimize power generation with renewable sources	User preferences and behavioral analysis for better optimization. Based on the user needs	The agent should prioritize equitable electric power supply for all users
Mobility	Coordination of public transport using geolocation. Private transport infrastructure automation. Customization of transport	Routing of trajectories based on user preferences: time, cost, comfort, etc.	The agent should use situational preference on routes and infrastructure, e.g., for emergency services. Prevention of high-risk situations like driving under the influence
Natural resources	Public monitoring and display of environmental data to reduce individual waste of resources	Tailored individual programs for resource savings. Public awareness	The agent should distribute natural resources equitably and penalize waste

Table 2 shows a comparison of a CPS and CPSS for a specific field but also how an AMA could improve the implementation. The first column is the subsystem within a smart city. The second column describes an example implementation of a Cyber-Physical System. The third column describes the added functionality when the social space is added in the Cyber-Physical-Social System. The last column describes how the Artificial Moral Agent may interact in the CPSS.

3 Discussion

The "inevitability" of automation in most activities' humans do makes us believe the necessity to develop AMAs. Not that every technological system may need a moral agent, but as the complexity level of AI increases, it will no longer be possible to know what they will do (or how they will react) in every situation. Thus, adding moral guidelines may prevent unwanted reactions and may also serve as guidelines for other humans. Moreover, it may prevent immoral use of the resources available or of the technology itself.

An implementation of an Artificial Moral Agent is still under development using machine learning algorithms. It is proposed to be added to the communication part between a Human Machine Interface that interacts between the user and all sensors and actuators found in a smart community. A smart city scenario could then be scaled by the integration of multiple communities each varying in size.

However, there are still some disadvantages of AMAs. To this day, it may not be possible to build a perfect moral agent as the technology tools are restricted on how to define ethics digitally. But this same restriction has not stopped the development of AIs from gaining expertise in diverse areas, so, perhaps, it will be the same case for morality. Another problem to face is that there is no universal agreement in ethics so it will not be possible to program it. Nonetheless, humans also face moral decisions where there is ethical vagueness, but it does not stop us to make moral judgments. Therefore, AMAs can also choose the best moral response with the information within reach.

4 Conclusion

CPS is mainly used as a technical solution in factories to increase productivity with less centered interaction between humans. However, adding a Social space for becoming a CPSS increases the human centralized interaction. A smart city environment is proposed as a CPSS where the citizens' needs become the center of the interaction. Moreover, the CPSS, instead of being modeled just as the integration of the social part in the system, is proposed to integrate an AI that acts as a moral agent to monitor and regulate the communication between all the spaces of the CPSS.

The moral agent implements a moral filter within the process of deciding the actions to implement; in this way, it can ensure not just a flawless technical operation of the proposed smart city environment but also an ethical operation as well.

Thus, this research paper does not try to substitute humans' moral responsibility in a smart city environment nor in its actions, but instead, proposes a path that could integrate the autonomous decisions making part, for the CPSS, based on moral aspects.

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