

Self-employment for autonomous robots using smart contracts

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Abstract—The physical autonomy of robots is well understood both theoretically and practically. By contrast, there is almost no research exploring a robot’s potential economic autonomy. In this paper, we present the first economically autonomous robot—a robot able to produce marketable goods while having full control over the use of its generated income. In our proof-of-concept, the robot is self-employed as an artist. It produces physical artistic goods and uses blockchain-based smart contracts on the Ethereum network to autonomously list its goods for sale in online auctions. Using the blockchain-based smart contract, the robot then uses its income from sales to autonomously order more materials from an online shop, pay for its consumables such as network fees, and remunerate human assistance for support tasks. The robot also uses its income to repay investor loans that funded its initial phase of production. In these transactions, the robot interacts with humans as a peer, not as a tool. In other words, the robot makes peer financial transactions with humans in the same way that another human would, first as an investment vehicle, then as a seller at an auction, and then as a shop customer and a client. Our proof-of-concept is conducted as an in-lab experiment, but gives rise to an important discussion of the legal implications of economically autonomous robots, which under existing frameworks can already be embedded in corporate entities that are classed as artificial persons.

I. INTRODUCTION

Robots and cyber-physical systems deployed in the real world are reaching increasing levels of autonomy and versatility. They can be programmed to perform tasks with little to no human intervention and can vary significantly in size, functionality, mobility, dexterity and intelligence. In general, physical autonomy (i.e., the ability to observe and act on a physical environment autonomously) is well understood and the state of the art is quite advanced, both theoretically and practically. However, the increasing physical autonomy of devices and systems in the real world opens up new issues beyond the physical environment: for instance, security, accountability, auditability, and other social and ethical issues [1]–[3]. In contrast to physical autonomy, very little research has been done on the social and economic autonomy (i.e., the ability to observe and act on a social or economic environment autonomously) of robots and cyber-physical systems.

The idea of economically autonomous robots has been explored in philosophical, social, legal, and economic theory. For instance, [4] defines a fully economically autonomous

robot as one that can use its generated income to cover the costs of its manufacture and maintenance and to reproduce itself. In the field of management and marketing, [5] explores the question of what happens when home robots and digital assistants not only make purchases on behalf of their owners, but take consumer responsibilities such as filtering goods and services for their owner to choose from. In the meantime, a novel line of research has begun to explore the concept of *machina economicus* [6], or rational AI agents that can reason in economic contexts—either as an ideal synthetic version of the perfectly rational *homo economicus* [7], or using new incentive mechanisms. An early practical example of this concept is the use of software agents for automatic trading or for AI-driven setting of market prices [8], in which AI agents might perform better economic reasoning than humans. The concept of *machina economicus* has also been expanded from artificial agents that mimic humans to the concept of *automata economicus*, in which artificial agents achieve new types of economic value creation and build an artificial “creative economy” [9]. The legal implications of economically autonomous robots are also being explored, e.g., legal personhood for robots [10], [11], robot-based tax systems [12], copyright and intellectual property rights of robot creations [13], [14], and whether robots need to obey copyright law [15]. Although some of these theory developments are more than a decade old, there have been limited practical advances, and no prototype of an economically autonomous robot has yet been built.

In this paper, we present the first proof-of-concept economically autonomous robot, i.e., a robot that can autonomously generate income by producing marketable goods or services and can use the income to autonomously maintain itself through the purchase of resources. Our economically autonomous robot is a self-employed robot artist that autonomously makes physical paintings, sells them in online auctions, and uses the income it generates to purchase supplies from an online shop, remunerate physical tasks from a human assistant, and repay start-up loans from initial investors. The proof-of-concept uses blockchain technology, through rules encoded as Smart Contracts (SCs)—computer code embedded in the blockchain that directly controls the transfer of digital assets between parties [16]. The control logic for the robot resides in the SC while the actuation takes place in the physical world.

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A. Blockchain-based robotics

The first proof-of-concept robotics system that used blockchain technology to make financial transactions was the ADEPT [17] protocol introduced by Samsung and IBM. The project focuses on increasing the autonomy of devices or machines that operate in a decentralized manner within (industrial) IoT. For their proof-of-concept, they used a washing machine (W9000) that could autonomously order detergent every time it ran out. The ADEPT project also led to a pilot of a Blockchain-of-Devices (BoD), where devices work together autonomously and make decisions about tasks or orders [18]. Along these lines, the *Plantoid* (2015) art project by Okhaos² proposed a metallic robotic sculpture designed to look and move like a plant and be displayed in a public space. If humans like the sculpture and make a small donation to it, the sculpture dances with plant-like movements and music and lights. Contributions are made via the Bitcoin blockchain. Once the sculpture has collected a sufficient quantity of Bitcoins in its crypto wallet, it will ask humans to help it by reproducing it (creating a new sculpture) and placing the “offspring” in a new location.

However, in the first example (ADEPT), the washing machine did not have control over the value or income used to complete tasks or make the orders, and in the second example (Plantoid), the robotic sculpture did not produce external goods or services nor did it make consumer choices and purchases autonomously. Moreover, its donation-based model might also lead to long wait times and deadlocks. In contrast, an economically autonomous robot must have control over the action of entering the market to offer goods or services and over the consumer purchases it makes using the income that it generates. Therefore, although these two projects are important precedents in devices making transactions using blockchain-technology, they are not economically autonomous robots.

Beyond economic autonomy, recent research has demonstrated many security and robustness benefits of combining autonomous robots with blockchain-based technology [19]–[21], using both SCs and Merkle trees. In these research works, the robots are used as nodes in a network and their interactions are encapsulated in cryptographic transactions. Blockchain technology can give data confidentiality and entity validation to robots [22], making them suitable for applications in which privacy and security are a concern [23].

In summary, previous literature has overlooked a prototype of an economically autonomous robot than not only directly manages its income generation and the resources it needs to maintain its creation of economic value (e.g., recharging batteries, paying for supplies), but also adapts to market needs. Historically, robots have participated in labor roles (e.g., in factories, assembly lines), but with new decentralized

²News articles on the *Plantoid* (2015) art project by Okhaos: in *Furtherfield*, “Plantoid: The Blockchain-Based Art That Makes Itself” by Robert Myers, available at <https://www.furtherfield.org/tag/autopoiesis>, and in *CoinDesk*, “This Robot Plant Needs You and Bitcoin to Reproduce” by Grace Caffyn, available at [```

graph LR
 1\(\(1\)\) --> 2\(\(2\)\)
 2 --> 3\(\(3\)\)
 3 --> 4\(\(4\)\)
 4 --> 5\(\(5\)\)
 5 --> 6\(\(6\)\)
 6 --> 7\(\(7\)\)
 7 --> 1
 1 --> 2
 2 --> 3
 3 --> 4
 4 --> 5
 5 --> 6
 6 --> 7
 7 --> 1

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Fig. 1. A) *Gaka-chu* (“painter” in Japanese), a 6-axis robot arm (KUKA KR6 R900) programmed using an Ethererum-based SC while painting a canvas. *Gaka-chu*’s work area dimensions are  $2.53 \times 2.57$  meters and are specially designed to maximize safety. B) Typical workflow for a painting job: (1) The robot uses its sensing, computation, and actuation capabilities to paint a canvas. (2) The robot puts the painting up for auction, participants can place their bids in the auction website. (3) A winner is selected when the painting process is finished and the final bid is deposited (by using ETH: the cryptocurrency of the Ethereum network). (4) Ownership of the painting is transferred to the winner of the auction. (5) The payment is transferred to the robot’s account. (6)-(7) The robot can order supplies from an art shop to maintain its painting activities.

financial tools such as blockchain-based SCs, robots can also take part in other aspects of our economic environment, redefining their role as not mere tools but potential peers.

### B. *Gaka-chu*: a self-employed autonomous robot artist

In this paper, we present an economically autonomous robot named *Gaka-chu*. *Gaka-chu* paints canvases, uses blockchain-based technology to sell the paintings it makes in online auctions, generates and collects income, and uses its income to purchase the material and labor resources needed to maintain its activity, all with minimal human intervention (Fig. 1). Finally, *Gaka-chu* is able to pay back initial investors. The three main challenges of an economically autonomous robot are that: (1) the robot should generate income to maintain itself, (2) the robot should have an mechanism that reacts and adapts to market changes, and (3) when interacting with third-party agents such as online shops or human bidders, the robot should do so as a peer, not as a tool. In this paper, *Gaka-chu* meets these three main challenges, demonstrated in a 6-month experiment.



Fig. 2. Workflow for topic selection: *Gaka-chu* first (I) selects the English keyword with the largest number of searches that day in Google Trends, (II) translates the keyword into Japanese characters, (III) converts the resulting text into an image, and (IV) uses the image as an input for the physical painting process.

Our findings show that *Gaka-chu* can reach economical autonomy: fulfil a job, get rewarded for it, and invest the benefits in its own sustainability.

The remainder of this paper is structured as follows. Section II describes (II-A) how the robot selects a topic for painting, (II-B) the sensing, planning, and actuation when painting a canvas, (II-C) how the online auctions are organized and financial transactions made, and (II-D) how the robot interacts with the autonomous online shop and human assistants to provide the robot with the necessary painting consumables and manual assistance. Section III presents the results of a 6-month experiment including a start-up “loan” from human investors, making and auctioning four paintings, and fulfilling financial transactions with webshops and human peers (customers, and assistants). Section IV discusses the results, especially the legal implications of economically autonomous robots and the relationship to existing frameworks of artificial legal personhood, and proposes future directions. Finally, Section V provides our conclusions.

## II. METHODS

As any artist painter, *Gaka-chu* has four main challenges: (1) how to select a topic for the painting, (2) how to actually paint it, (3) how to sell the painting to obtain economic resources, and finally, (4) how to use the generated income to purchase the necessary materials and assistance to continue with its activity. All involved software described in this section is available at our public GitHub repository<sup>3</sup>.

### A. Selecting a topic for a painting

Each painting by *Gaka-chu* consists of a set of kanjis (i.e., Japanese characters) which together form a keyword. *Gaka-chu* adapts to the market by choosing the kanjis based on keywords that are popular in Google Trends. The topic selection process (Fig. 2) proceeds as follows: (I) *Gaka-chu* requests the keyword with the maximum number of searches for the current day from the Google Trends<sup>4</sup> API. (II) *Gaka-chu* translates the selected keyword to Japanese using the Google Translate<sup>5</sup> API. (III) *Gaka-chu* converts the text-based Japanese kanjis into an image of black strokes (forming the kanjis) in the center of a white background, using the Python Image Library (PIL) [24], and (IV) saves the image for further processing. In this approach, *Gaka-chu* chooses topics that are generally popular and potentially profitable for sale, and still the paintings are not associated with any previous copyright claims.

<sup>3</sup>Github repository: <https://github.com/Multi-Agent-io/gaka-chu.online>

<sup>4</sup>Google Trends: <https://trends.google.com>

<sup>5</sup>Google Translate: <https://translate.google.com>

### B. Painting process

After an image of the selected keyword is created and stored, *Gaka-chu* starts the physical painting process. The three main components—sensing, planning, and actuation—are depicted in Fig. 3.

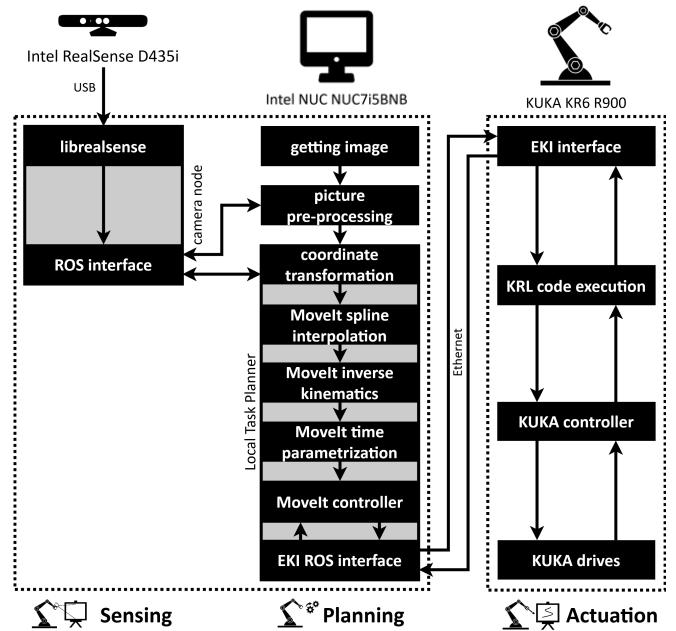


Fig. 3. Functional scheme and workflow for the *Gaka-chu* painting process. In summary, the sensing part gets the information about the canvas (e.g., position, orientation) from a depth camera installed at the end-effector. This information is sent to the planning part, which runs in an Intel NUC single-board computer and calculates all trajectories for the *Gaka-chu* joints. Finally, in the actuation part, calculated trajectories are sent to the internal motor controllers, which execute the movements.

1) *Sensing*: In the sensing pipeline (see the left block of Fig. 3), a depth camera (Intel RealSense D435i) is mounted on *Gaka-chu*'s end-effector and connected to a single-board computer (Intel NUC7i5BNB) via USB. The position and orientation of the canvas is detected from the point cloud information from the depth camera (Fig. 4). This process is handled by a ROS [25] camera node, working in client-service mode and based on the realsense library<sup>6</sup>. The ROS camera node also publishes the dimensions and center point of the canvas which are necessary for the correct coordinate transformation from the canvas to the camera frames. It then provides this information upon request to the planning component of the system through its ROS interface.

2) *Planning*: In the planning pipeline (see the center block of Fig. 3), *Gaka-chu* calculates the end-effector tra-

<sup>6</sup><https://dev.intelrealsense.com>

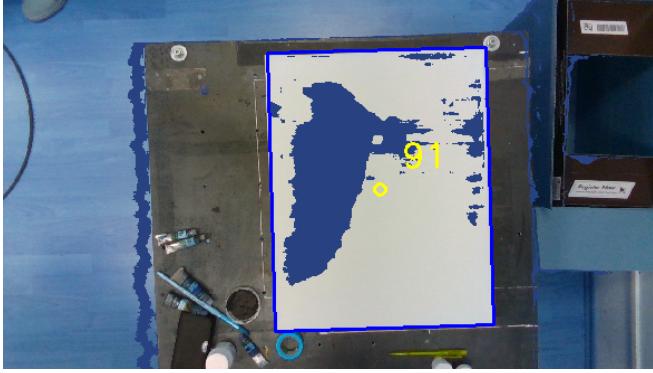


Fig. 4. An example of canvas detection using the Intel RealSense D435i depth camera. The image shows the angle of rotation of the canvas relative to *Gaka-chu*'s horizontal axis.

jectories needed to paint the image generated in Sec. II-A. First, *Gaka-chu* pre-processes the stored image by converting the binary 2D shapes of kanjis into 1D curves, i.e., “skeletonization” [26] (Fig. 5 A and B), using the OpenCV library [27]. The 1D curves are represented as pixels in a 2D coordinate frame. The pixel coordinates are passed to the Local Task Planner (LTP), which translates the pixels of the skeletonized image from their starting image-based coordinate frame to *Gaka-chu*'s canvas coordinate frame, with the  $z$  axis taking into account the 3D position of the canvas relative to *Gaka-chu*. Then, the LTP converts the coordinates from pixels to meters. At this point, *Gaka-chu* has all the necessary coordinates to paint the strokes that will form the desired painting.

For *Gaka-chu*'s motion planning, we use the MoveIt Framework [28], with a customized MoveIt module for inverse kinematics. Our custom module extends the standard module by taking into account that the manipulator in different positions has different kinetic energy (i.e., the moment of inertia changes). This would eventually lead to blockage of the movement by the KUKA internal controller. First, the planner interpolates paths to build splines relative to the end-effector coordinate system. Our MoveIt module solves the inverse kinematics and obtains paths for each link of the robot. The motion planner then conducts time parameterization, taking into account the maximum speeds and accelerations for each link of the robot, and finally prepares the calculated trajectories to be sent from ROS to the Ethernet KRL Interface (EKI)<sup>7</sup>.

**3) Actuation:** In the actuation pipeline (see the right block of Fig. 3), *Gaka-chu*'s internal computer runs executable code written in the KUKA Robot Language (KRL)—a programming language similar to Pascal. The KRL program receives the trajectory information calculated in the planning pipeline through the EKI interface and organizes the transfer of the necessary rotation angles, speeds, and accelerations to the KUKA drives. If the controller detects any problems during the movement (e.g., physical impossibility of movement), the manipulator stops and the corresponding error messages

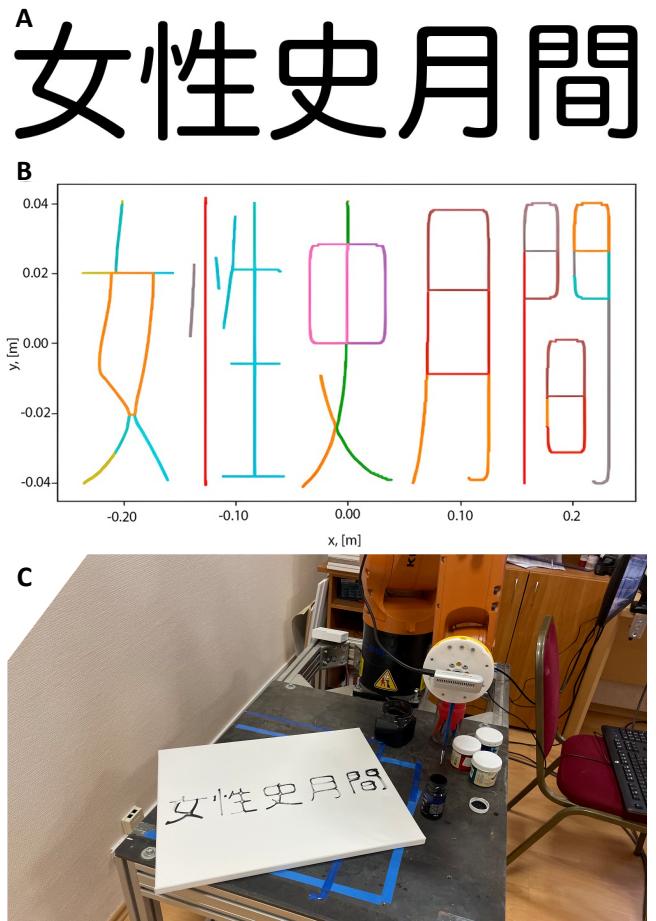


Fig. 5. An example of the skeletonization and painting process. (A) 5 kanjis form the Japanese term 女性史月間 obtained after translating the Google Trends keyword “Women’s History Month.” (B) The same image after skeletonization of the 2D shapes into 1D curves and conversion from pixels to meters. Different colors represent different strokes in the painting process. (C) An image of the finished painting.

are sent back.

The technique *Gaka-chu* uses to paint the canvas is based on the existing literature on drawing with strokes [29], [30]. The paint cup is installed at a known position, to one side of the manipulator. The painting algorithm is organized as follows: (1) the robot moves to the position above the paint cup, (2) it dips the brush into the paint and withdraws it, (3) it moves to the starting point of the trajectory with a slight offset along the  $z$  axis, (4) it descends to the starting point, (5) it paints one segment of the trajectory, and (6) it raises the brush and repeats the process until the whole painting is complete (Fig. 5 C). After testing several types of paints and brushes, we realized that nylon and bristly brushes as well as acrylic paint show the best finishing quality.

### C. Generating income: selling paintings

After the painting has been completed, *Gaka-chu* puts it up for sale in an online auction. The online auctions are hosted on an external service, where *Gaka-chu* maintains its own page<sup>8</sup>. The logic of the auction is encoded in

<sup>7</sup>EKI is a TCP/IP protocol which allows the exchange of XML and binary data between the manipulator and the external system.

<sup>8</sup>Rarible auction page: <https://rarible.com/gakachu>

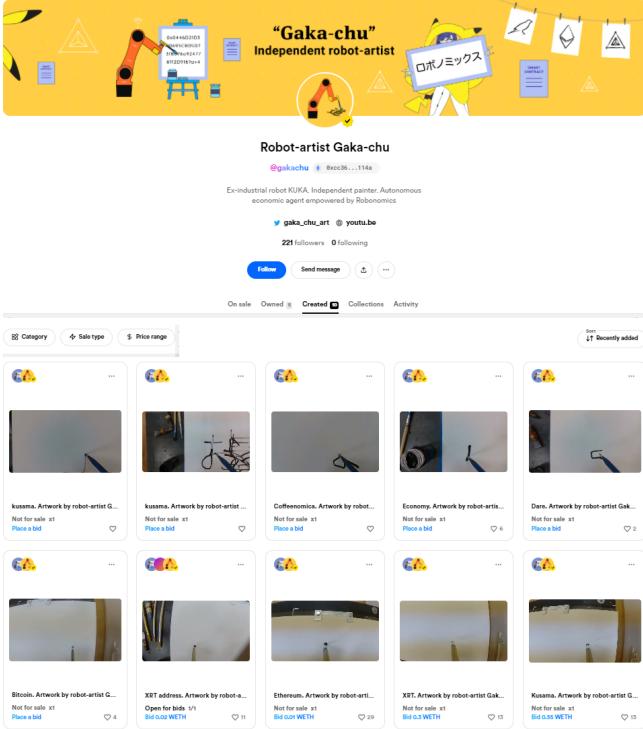


Fig. 6. Screenshot of the auction site where *Gaka-chu* advertises the completed paintings. Potential customers bid with their own blockchain-based assets until the auction closes and the highest bidder wins the auction lot. Four completed auctions, illustrated in the balance graph, are located at the very end of the list.

an Ethereum-based SC<sup>9</sup> and is uploaded in the Ethereum Mainnet blockchain.

When a painting is completed, *Gaka-chu* advertises its availability by creating a dedicated tab for it within its own page and uploading a video of the entire painting process. Human bidders are then able to place bids in a given time limit in ETH (i.e., the cryptocurrency of the Ethereum blockchain) using their own crypto wallets. Once the auction is closed, the ownership of the painting is assigned<sup>10</sup> to the Ethereum address of the highest bidder, and the bid amount is sent to *Gaka-chu*'s Ethereum address. The process of arranging shipping and delivery of the physical painting to the mailing address of the highest bidder is of course arranged off-chain, with the manual help of a human assistant remunerated by *Gaka-chu*.

#### D. Using income: purchasing consumables and paying back investors

*Gaka-chu* can use its generated income to order the art materials needed for future painting jobs (e.g., canvases, paints, brushes) and to hire human assistants. *Gaka-chu* autonomously places orders at an online art shop that accepts payments in ETH by using a web-app we developed<sup>11</sup>. *Gaka-chu* decrements its canvas stock counter each time

<sup>9</sup><https://docs.rarible.org/ethereum/smart-contracts/smart-contracts/>

<sup>10</sup>Digital ownership is assigned using a non-fungible token (NFT). More information is available at [www.gaka-chu.online](http://www.gaka-chu.online).

<sup>11</sup>Art shop interface: <https://dapp.robonomics.network/#/art-shop>

it completes a painting, and decides to purchase a set of supplies (canvases, paints, and brushes) when the counter reaches one. Using this software, *Gaka-chu* generates a message containing the composition of the order, the Ethereum address, and the amount of ETH tokens to be paid, and sends the message to the art shop through its server API. If the parameters for the purchase are acceptable, the art shop agrees to execute it. All steps in this two-way communication are conducted through an Ethereum-based SC, obliging the art shop to fulfill its liabilities to provide consumables. The SC ends with the sending of a final message about a successful purchase and the sending of ETH tokens to the shop's Ethereum address. When supplies are received by post, a human assistant paid by *Gaka-chu* places the canvas, paint, and brush in their positions. The human assistant is remunerated with ETH that *Gaka-chu* sends to the human's crypto wallet. Finally, after successfully selling a batch of paintings, *Gaka-chu* pays back the initial investments that were used to start its activity (e.g., pay for the auction site platform and sign-up fees).

### III. RESULTS

To demonstrate the feasibility of an economically autonomous robot, we ran a 6-month experiment in which *Gaka-chu* received a starting “loan” from early human investors, painted canvases and sold them at auction to human bidders, used the generated income to maintain its economic activity by purchasing supplies and manual human assistance, and paid back its human investors. During the experiment, *Gaka-chu* painted four canvases which were put up and sold at online auctions.

Figure 7 shows the balance changes on *Gaka-chu*'s Ethereum wallet<sup>12</sup> during a 6-month period of time (March to September 2021). Initially, in order to setup an account on the auction site, *Gaka-chu* requires to send several transactions and pay network and platform fees (grey dots). For that purpose, *Gaka-chu* received an initial “loan” from human investors (red squares transactions). *Gaka-chu* then sold four completed paintings at different auctions, transferred the ownership of the paintings to the highest bidders, and in return received the corresponding bid amount in ETH (green diamonds). *Gaka-chu* was then able to pay back its human investors (orange square), purchase more art supplies (blue triangles) and pay for assistance and operational fees (yellow dots). The videos of all *Gaka-chu*'s completed paintings and results of its four closed auctions can be retrieved from the auction host website.

### IV. DISCUSSION

#### A. General discussion

Robots of all types, from autonomous vehicles to 3D printing devices, are revolutionizing a wide variety of industries: mobility, manufacturing, and logistics. The emergence of robotics is commonly acknowledged as one of the main disruptive changes that will have substantial socioeconomic

<sup>12</sup><https://etherscan.io/address/0xcc3672c869c923b90f2c1bfba2c7801e3924114a>

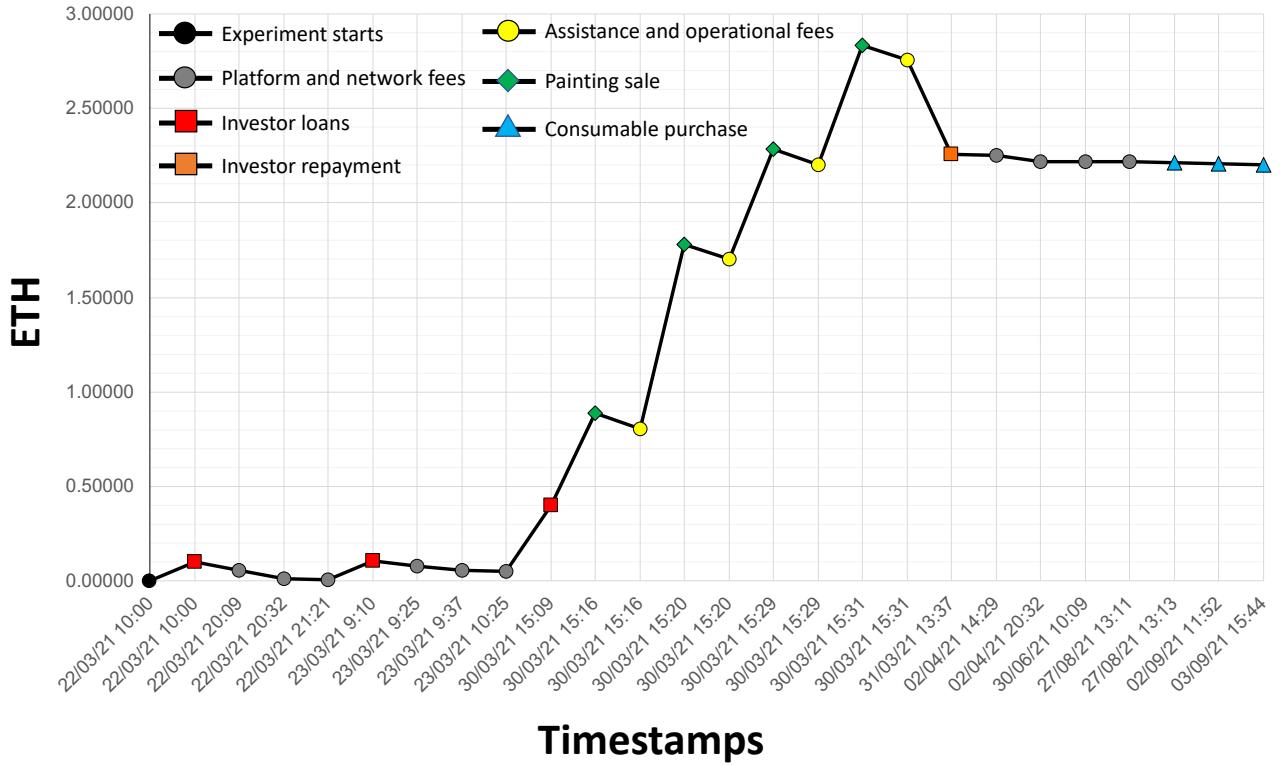


Fig. 7. Balance on *Gaka-chu*'s Ethereum wallet from March 22<sup>nd</sup> 2021 to September 3<sup>rd</sup> 2021. In the figure, red squares represent transactions from initial investors to fund the system. Green diamonds represent the sale of a painting. Blue triangles represent the purchase of supplies for the next jobs. Grey dots, represent the payment of network fees and logistic fees. Yellow dots represent human assistance and operational fees. Finally, the orange square represents “loan” repayment for the initial investors.

impact in upcoming decades [31]. As countries and companies attempt to recover from the COVID-19 pandemic, interest in robotics will continue to increase—automation is key to improving productivity. In the one hand, financial software-based agents (e.g., Paypal, High Frequency Trading, eCommerce) have had a huge impact on productivity, but they do not impact the physical realm directly. On the other hand, modern robots and cyber-physical systems interact with the physical world in powerful ways (i.e., sense, plan, and actuate), but they lack the technical ability to directly participate in financial transactions due to insufficient agency.

However, Blockchain-based technologies such as SCs allow robots to become online, digital economic actors that can financially operate with minimal human intervention. The combination of both fields opens the door towards financial autonomous robots that can redefine their role as not mere tools but potential peers. This opens a debate not only about the concept of property and ownership under increasing robot autonomy but also whether these systems can become a future cornerstone of societal economic activity (e.g., a Universal Basic Income [32] through taxation of robot’s economical activities).

### B. Legal implications

In addition to technical and economic considerations, the topic of self-employed robots raises several important

questions related to legal viability<sup>13</sup>. In a traditional business environment, to autonomously purchase supplies and assistance as well as sell goods and services, a robot would need many of the commercial rights that humans enjoy. However, present legal frameworks do not allow robots to sign contracts on their own behalf [33], a key to commercial transactions. Also, robots are not currently allowed to own money or property—these rights are historically reserved for “natural persons.” In addition, robots that create works are not allowed to own the resultant Intellectual Property (IP). For instance, machines that write articles, stories, or books cannot receive copyright protection [34] and U.S. federal courts have held that machines cannot be listed as the inventor in U.S. patents, requiring the inventor to be a natural person [35].

However, law does not restrict commerce or IP exclusively to humans. Indeed, “artificial persons” have existed in law for hundreds of years [36]. Many jurisdictions recognize personhood rights in inanimate objects, such as landmarks or animals, and certain jurisdictions even provide personhood to ships, temples, and church buildings [37]. Yet, the most common grant of rights to “artificial persons” is the treatment of corporations as “persons” in law under certain circumstances. Corporations may own bank accounts, sign

<sup>13</sup>For the sake of simplicity, this section will discuss the legal aspects of this research based on the laws and jurisdiction of the United States, to illustrate the general global trend in this matter.

contracts, and engage in commerce in the same ways as natural persons [36]. Although a company may not be an author or inventor, people are able to assign copyrights or trademarks to companies. Companies can be the owner, purchaser, or seller of IP rights. Even though the concept of a corporation as a “person” is a legal fiction, nations have protected the authority of corporations as “artificial persons” to achieve commercial goals and promote commerce.

Because corporations are already considered “artificial persons” under many current legal frameworks, we might be able to legally achieve several of the autonomy goals presented in this work, by incorporating new technology (e.g., blockchain-based SCs and robotics) into corporate dynamics. As an example, incorporating a robot would allow the machine to act on behalf of a corporate entity, not dissimilar from the way that people complete commercial transactions online today. For example, when a user makes a purchase from Amazon through its online store, it is a person completing a contract by conducting a transaction through Amazon’s software. The software is an electronic agent on behalf of the company, and the transaction is legally binding even though there is no natural person signing the contract. In addition, a corporation is able to enforce its rights in court (e.g., file lawsuits or serve as a defendant) in a way that machines currently cannot. In this regard, a “corporate robot” would be able to purchase, sell, and hold trademarks, patents, and copyrights. For IP created by machines, the company can involve a human writer or inventor as a third party in the same way that the robot in our proof-of-concept secures human assistance. In this scenario, the human assistant could file applications for IP protection, then assign any IP to the company associated with the robot. However, there are still some legal restrictions on full autonomy—for instance, traditional corporations are still required to have boards of directors which are required to be natural persons.

However, new legislation is being created to extend the autonomy of robots (both software and hardware based) in the corporate world. In the United States, Wyoming recently recognized a new legal entity called a Decentralized Autonomous Organization (DAO) LLC<sup>14</sup>: an artificial person in law, with the right to sue, be sued, and own property that could be explicitly managed by an algorithm. Simultaneously, the United Kingdom’s Parliament is reviewing a flexible framework for regulatory bodies to provide case-by-case context-sensitive guidance to assign legal liability and personhood for AI systems [38]. Under this framework, legal validity could be provided for a limited number of exceptions to be made for specific products and services (e.g., financial or legal advice) that are within clearly defined contexts.

In this research, we showed that blockchain-based technology such as SCs provides robots with the technical foundation to become economically autonomous actors. In addition, current legal frameworks allow robots to engage in certain commercial actions. However, robots cannot hold

liability or IP rights for any of the services or works they provide, which might represent an obstacle to moving this technology from pure academic research to real-world deployments. A possible way forward is to enclose a robot in an existing “artificial person” such as a corporation. In this case, the robot could be allowed by the company to complete financial transactions with some autonomy, and the company would have legal accountability for the robot. A foreseeable future might include for-profit organizations managed by autonomous entities that provide digital or tangible services. These organizations would provide a new way of building autonomous systems in which robots are no longer constrained to the labor field but expand to the capital and investment domain to become “entrepreneurs.” However, in this context, it is key that new legislation foresees this possibility and creates guarantees that these systems are secure, safe, and explainable. One of the aims of this paper is to highlight this need, because future studies will require tight collaboration between the legal, social, and technological disciplines.

### C. Future Work

For future work, we would like to focus on improving the selection of the keyword to paint and after a series of sales, the topic selection strategy could be adjusted based on historical data. In addition, financially autonomous robots also need to be able to make purchases to maintain their continued viability. For instance, future robotics systems using this technology might need to be able to pay for electricity (e.g., to a street charger), spare or replacement parts (e.g., to Mouser), training data (e.g., to MTurk), or skilled human resources (e.g., to TaskRabbit) with their blockchain-based financial assets. Developing new payment gateways and interfaces to these services is a promising way forward.

## V. CONCLUSIONS

In the robotics research field, physical autonomy (i.e., the ability to observe and act on a physical environments) is well understood and the state of the art is advanced. However, very little research has been done on the economic autonomy of robots. In this work, we have presented and demonstrated the first economically autonomous robot, using blockchain-based smart contracts. In our proof-of-concept, the control logic for the robot is embedded in a smart contract on the Ethereum blockchain network and the actuation takes place in the physical world. The robot makes physical paintings, sells them to humans in online auctions, and uses the income it generates to purchase supplies from an online shop, remunerate a human assistant, and repay initial investors. In other words, during the 6-month proof-of-concept experiment, the robot demonstrates economic autonomy: it fulfills a job, gets rewarded for it, and uses the benefits to fund its own sustainability. Finally, we discuss the legal implications of economically autonomous robots, which under current frameworks could be embedded in existing “artificial person” entities such as corporations.

<sup>14</sup>The statute enacted into law by Wyoming can be found here: <https://wyoleg.gov/2022/Enroll/SF0068.pdf>

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