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On IOTA as a potential enabler for an M2M economy in manufacturing

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Abstract

Recently, the manufacturing industry became aware of distributed ledger technologies, a protocol that, amongst other things, allows trustless transactions between machines. In this paper, we investigate whether an M2M economy would be feasible within the IOTA network, a popular cryptocurrency for IoT. We build and present a simple industrial lot-size one production system involving three agents that cooperate to create an artistic painting. Payments between agents and users are autonomously executed via IOTA. Amongst other points of criticism, we found that an M2M economy would benefit from the support of smart-contracts and conclude that IOTA is not a fitting solution.

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Keywords: Distributed ledgers; Blockchain; IOTA; Directed acyclic graphs; Machine-to-machine; Decentralized smart economy; Internet of things; Smart contracts

1. Introduction

Since the rise of cryptocurrencies, there have been numerous discussions about how they could redefine classical business models. The world economic Forum considered blockchain to be among the computing "mega-trends" that are likely to shape the world in the coming decade [1]. Pricewaterhouse Cooper (PwC) even named blockchain the biggest disruptor to industries since the introduction of the Internet [2]. Despite this hype, almost no use-cases have been successfully deployed in the field of production engineering. The manufacturing sector faces the challenge of growing rivalry from lower-wage countries while consumers demand more customized production in shorter time. In order to remain competitive in high wage countries, it either needs to offer something low wage countries do not offer or needs to become more autonomous and thereby reduce the number of employees needed to produce its goods. This motivates research into realizing an autonomous Machine-to-Machine (M2M) economy. As illustrated in Fig. 1, customers could design their product and the machines themselves would order and pay for parts, services, or devices required to build it. In any economy, this process would continue recursively in a group of participants until arriving at the lowest level of the production chain. The innovation of M2M economies is that they could allow that to happen without human intervention and thus with far less overhead in time and cost. In such a customizable production environment, sub-tasks need to be distributed and executed and payed for quickly, reliably and efficiently. This concept bears a few problems; among these is the software infrastructure required for communication between these agents. Other problems include further automation of dynamic factory processes, automated decision making, and negotiation and successful trade. However, this paper solely focuses on the problem of communication and payment. Like humans in a traditional economy, machines would require a way to transfer monetary value in an M2M economy. But our current centralized verification systems are likely not scalable

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enough to support millions of microtransactions per second efficiently, which devices like sensors would require to sell data in small batches. Thus, it is encouraged to find new, scalable ways to transfer value while still knowing that transactions are trustworthy.

In this paper we investigate whether IOTA, a crypto-currency especially known for advertising itself as made for the Internet of Things (IoT) can be used effectively for end-to-end M2M payments and communication in such a setup to-date. We built a prototype M2M ecosystem based on our previous project "smART – a robotic artist" [21] and IOTA. The M2M version of smART (see Fig 5.) consists of the following three agents that together produce an artistic painting of a digital image given by the costumer:

1. A simulator and management node that can turn any picture or image into a series of instructions for an industrial robot arm to paint that image using acrylic paint,

2. an industrial robot arm,

3. a material supplier delivering colour, water, and other utilities.

2. Machine-to-Machine (M2M)

Within an M2M economy, agents, described by Lan and Wang in [18] as autonomous, goal-orientated software processes communicate with each other. Large-scale M2M communication aims to connect billions of devices around the world [4], each potentially following its own agenda and making decisions based on a given heuristic or self-learning algorithm. The Internet of Things (IoT) is just another widely used term for a similar concept. Its long-term vision is that machines and "things" interact, trade, and exchange information over Internet similarly to how humans do that today. The Internet shall become a hub in which devices exchange data autonomously with each other and with people [5]. Within defined legal boundaries, machines shall be able to autonomously share data on public data marketplaces. This offers new business models based on large-scale data-exchange creating information products [14].

The IoT and various other related technologies enable the M2M economy. Several critical machines are fitted with wallets and enabled to pay for required services and information. In an economy like that, devices can offer their services to each other over the Internet, passively earning money for their owners. Sensors to measure e.g. weather data could offer data they collected to devices that calculate weather models based on it. In an M2M economy, machines act as business partners on behalf of the person owning them. Just like cloud computing provided cheaper and more efficient access to computational resources, cloud manufacturing may provide cheaper and more efficient access to production resources and data by allowing very specialized facilities to make microtransactions with other specialized facilities when something is needed. This rapid ongoing development is reshaping how economic actors within a value chain interact with one another [14].

3. Distributed Ledger Technologies

A distributed ledger is a distributed database of a history of transactions that is agreed upon by the majority of the participants in its network through a pre-defined consensus-mechanism. All participants within a network have their own identical copy of the ledger. Any changes within the ledger are reflected in all copies eventually. The assets recorded within a ledger can be financial, legal, physical, electronic, or of many other natures. Depending on the rules of the network, the ledger can be updated by some or all participants. The predominant problems of security and consensus are generally solved through cryptographical mechanisms [6].

Some distributed ledgers employ a data structure called blockchain (Fig. 3a), storing and transmitting data in bundles of transactions called blocks, which are cryptographically linked to each other in chronological order. Blockchains record and synchronize data across the network in an immutable manner. As the blockchain grows (i.e. new blocks are added), earlier blocks and thereby transactions cannot feasibly be altered by any network member [7].

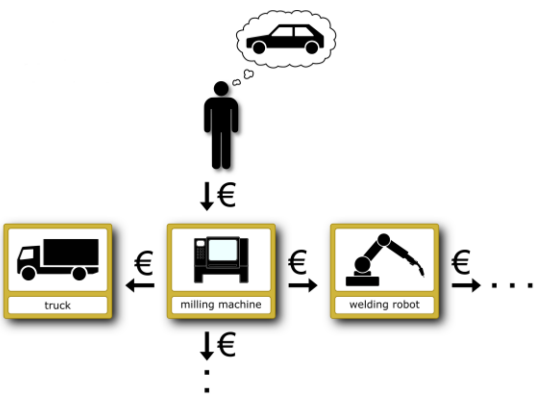

Fig. 1. Depiction of an M2M communication

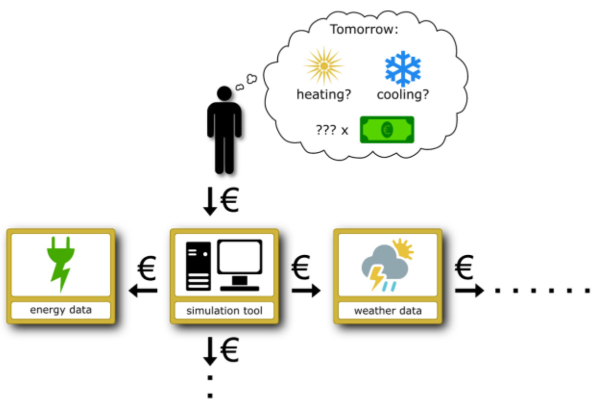

Fig. 2. Depiction of a data driven M2M economy

Various digital currencies like Bitcoin are based on blockchain, while IOTA amongst others uses a directed acyclic graph (DAG) (Fig. 3b). A blockchain is essentially a restricted version of a DAG, allowing connections only on a single-trajectory. IOTA's DAG, the "Tangle", does not bundle transactions in blocks, but rather views each transaction as its own block. Whenever a participant wants to add a new transaction to the Tangle, its sender must approve two previously appended, but unapproved transactions. The more transactions that attach to a new transaction are approved, the higher the confidence in the validity of the transaction becomes. Note that IOTA is asynchronous, meaning that nodes do not necessarily see the same history of transactions at all points in time. Transactions can therefore be conflicting, which is handled as described in [8, 17].

In Bitcoin, each block is verified by external participants often referred to as miners via a process called proof-of-work (PoW) [15]. This involves cracking a cryptographic hash via brute force computation. Miners who successfully find the solution to said problem, are rewarded with a small number of coins. Whenever two or more miners find the solution simultaneously and thereby both gain the right to append the new block or transaction, a "fork" occurs [9]. This ambiguity is resolved after one forked chain has more blocks or transactions added to it than the others. The network will then naturally select it as the new main chain and abandon the others, thereby restoring consensus [10]. PoW enables trustless and distributed consensus, meaning that participants don't have to trust in third-party services (e.g.: banks) to send or receive money from someone you don't know.

While Bitcoin encourages external miners, IOTA wants the senders themselves to do the computational work. For instance, in the example subnetwork of the Tangle in Fig. 3b, the sender of transaction 6 needed to solve small PoW problems to validate transactions 2 and 3 for transaction 6 to be appended to the Tangle.

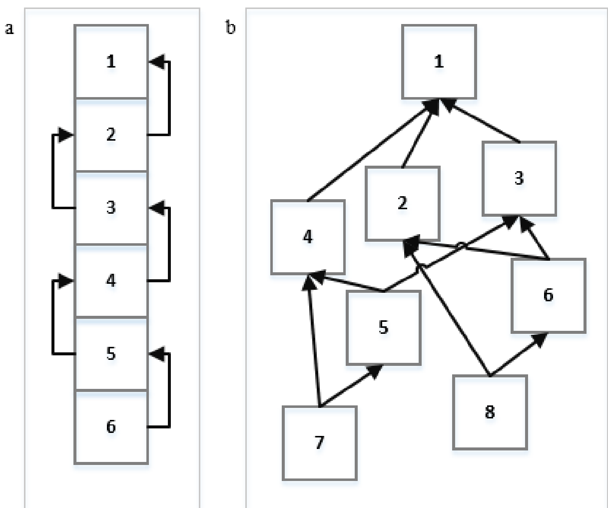

Fig. 3. (a) Depiction of a Blockchain; (b) Depiction of a DAG

When appended, transaction 6 starts out as an unverified leaf-node. To graduate to a confirmed transaction, it itself needs to be confirmed by 2 other network participants trying to append new transactions. The trust in a transaction increases, the longer the shortest path from it to a leaf node is [8].

The recent popularity of cryptocurrencies increased the computational power and thereby electrical energy consumed by mining operations drastically. This is a source of massive criticism, with some arguing that PoW is a waste of resources [16]. This problem implies that PoW might not be a good consensus-mechanism for the IoT, where orders of magnitude more transactions would occur than are happening across all cryptocurrencies to-date. Naturally, alternatives surfaced; one of them is proof-of-stake (PoS) [15], an algorithm that judges a participant's trustworthiness based on his or her wealth (i.e. stake). This process, while introducing new questions regarding the value of the achieved consensus, alleviates the problem of energy consumption [15]. A related alternative is proof-of-authority (PoA) [22], a mixture of modern centralized and decentralized consensus mechanisms.

4. Practical evaluation of IOTA in an M2M economy

We present a simple setup[1 2] that combines lot-size one production with industrial robotics and executes payments over IOTA autonomously. This project is based on smART [21], a robotic arm that can paint any image given using acrylic paint. smART consists of two main components: the physical setup (Fig. 5) and an algorithm that transforms a digital image into a sequence of robot-instructions that create a painting of that image. In this section, we will introduce smART and describe how we turned it into a small IOTA-based M2M ecosystem.

4.1. Neural Style Transfer & Iterative Stroke Sampling

First, the input image, which we will from now on call target image, is stylized towards an artistic style typical for paintings using Neural Style Transfer (NST) [13]. An example of such a transformation is given between Fig. 4a to Fig 4b.

Going from Fig 4b to instructions for a robot to execute requires bridging between reality and a digital simulation environment. smART solves this by learning a library of strokes, formally defined as a motion-path (the movement that produces the stroke) and a corresponding black/white image (the opacity of the resulting stroke). For the details of this process, please refer to [21]. Note that the set of strokes learnt is general, thus requiring the execution of this process only once (i.e. not for every painting).

An algorithm we call Iterative Stroke Sampling (ISS) [21] now uses the opacity maps of all strokes in the learnt

[1] http://project-smart.org/
[2] https://github.com/TinkeringCode/smART

set to run an iterative simulation in which the stylized image (Fig 4b) is approximated. ISS chooses strokes iteratively based on samples obtained using a carefully tweaked heuristic and an error-function that evaluates how much closer a stroke brings the simulated painting to the stylized image (details in [21]). This simulation returns 2 values: the simulated painting (Fig 4c) as well as the sequence of strokes executed with their corresponding position offset, rotation, and colour. The latter can be converted to robot instructions by considering the motion-paths associated to the strokes in this sequence.

Support motions like changing colour or the brush used, cleaning brushes, etc. are inserted into the code between strokes automatically. For instance, smART gets colour before every stroke and cleans its every time brush before unmounting it. This set of instructions is then converted to RAPID code, ABB's internal robot programming language, to be executed on the robot. The full code for all of the components described in this section (i.e. without the IOTA components we will shortly introduce) can be found at [21] and a video of it painting at [23] (also yet without the IOTA component).

4.2. Mechanical setup

The setup, depicted in Fig 5, contains an ABB IRB 120-3/0.6 industrial robot (a in Fig. 5) with a maximum reach of 580mm [12]. The robot is equipped with a Schunk NSR robot coupling system (b) that operates at 6 bars pressure [11]. The coupling system allows the robot to switch between three brushes of different sizes that reside in (e). The robot paints on DIN-A3 paper fitted on a wooden plate in front of it (c).

Fig. 4a Sidney's opera as a target-image

Fig. 4b. After Neural Style Transfer (NST)

Fig. 4c. Simulation result of Iterative Stroke Sampling (ISS)

The material provider agent (d) consists of eight buckets containing different colours. Note that the buckets are fitted with electrically controllable covers to protect the colours from drying out. A cleaning station (f) is connected to a water pump controlled by the material provider.

4.3. Machine-to-Machine communication

The signal communication between the material provider and the ABB robot arm runs over the robots' I/O pins. Requests for colour (i.e. opening a bucket for a brief period) and starting the water pump can thus be sent efficiently. In a real-world deployment, this would likely be preferred to occur over a protocol based on smart-contracts [20], which IOTA does not provide at the time of writing. Both the robot and the material provider handle payments over IOTA's Tangle. The robot can issue payments on its own using the API provided by IOTA, acting autonomously as soon as the user confirms and pays for his or her order.

4.4. Process flow

When ordering, the user sends the image they want to be painted to smART's public interface. The underlying agent of this interface is responsible for managing data flow and simulations. This managing agent now outsources the painting process to a smART-compatible robot. It sends information about motion instructions and material required to the robot, waiting to get an offer back. Analogously, the robot contacts his providers autonomously and computes the final price. If the user decides to order the painting after receiving their offer and the result of the ISS simulation, the orders are confirmed and payed for recursively, with each waiting for the incoming ones to be confirmed on the Tangle first. After all payments are executed, the robot starts painting and, after finishing, orders the resulting product to be picked up and shipped to the user.

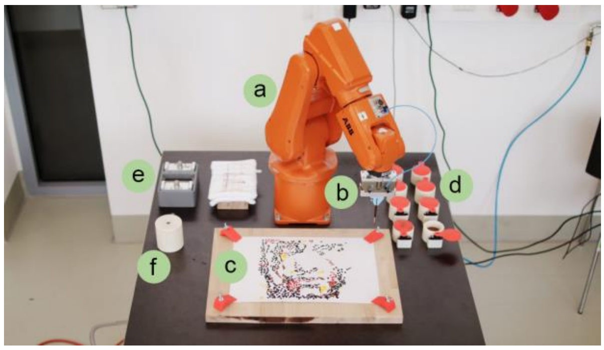

Fig. 5. Complete setup of the use case

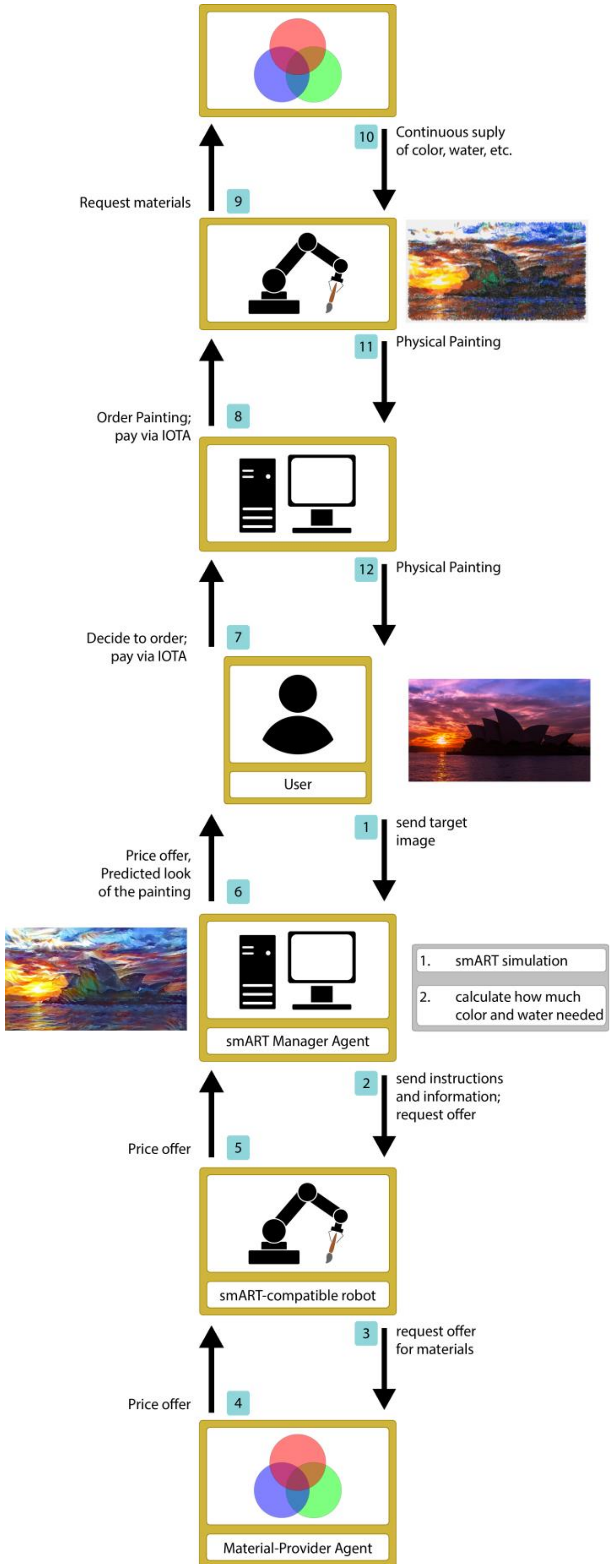

Fig 6. Process flow

5. Conclusion and future research

In this paper, we presented a toy use-case to investigate the practicality of the cryptocurrency IOTA as the basis for a machine-to-machine (M2M) economy. Despite IOTA being a very popular project within the industry, our conclusion is, that it is not yet ready to enable an M2M economy or the IoT. This is foremost due to the lacking support of smart-contracts to handle conditional transactions but also due to the environmental concerns that would be associated with a large-scale deployment of an IOTA-based M2M economy. Although practicality is the primary concern of this work, note that IOTA's coordinator [8] removes all benefits regarding decentralized and trustless decisions. Despite the conclusion that the applicability of IOTA on a real-world scale is very limited to-date, the opportunities for future research, however, are diverse. We conclude that smart-contracts are a necessity for an M2M economy to be feasible although some parties question their enforceability [19]. Further, we encourage working with systems that rely on proof-of-stake or proof-of-authority as these would cause smaller environmental damage at scale. In the future, we plan on implementing such technologies into similar prototypes as the one discussed in this paper, hoping to achieve a higher degree of autonomy and efficiency with regard to the communication and payments between agents.

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