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A smart combination of IoT and blockchain enabling technologies to measure and improve workplace safety in dairy farm

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ABSTRACT
In 2022, there was a 25.77 % increase in work-related accidents reported in Italy, including 1090 with a fatal outcome. Legislative Decree 81/100 regulates worker safety and requires employers to assess risks and implement necessary interventions. When risks cannot be eliminated, employers must provide appropriate Personal Protective Equipment (PPE). However, safety management requires large investments and supervision to ensure proper use of PPE. The current regulatory system, which focuses on punishing noncompliance with safety requirements, has been insufficient in deterring workplace accidents. To address this, the National Institute for Insurance against Accidents at Work (INAIL), is introducing incentives and substantial discounts on insurance costs for companies that carry out preventive actions. In this paper, the authors propose an innovative tool that leverages IoT and Blockchain technologies to record safety-related events in an immutable and transparent way, quantifying the level of achieved safety. They suggest setting up a system consisting of PPE with RFID technology and an automated surveillance agent to record operations and issue consents. The number of events recorded in Blockchain can quantify the degree of achieved safety.

Section: RESEARCH PAPER

Keywords: Internet of Things; blockchain; RFID; wireless communication; measurement; safety

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1. INTRODUCTION

In 2022, there were 697,773 work-related accident reports in Italy submitted to the National Institute for Insurance against Accidents at Work (INAIL), [1] the body that manages workers' insurance, 25.77% more than in the same period in 2021, including 1,090 with a fatal outcome. In practice, three people lose their lives every day due to workplace accidents. A true national emergency that has made increasingly urgent the need to carefully address the problem. Legislative Decree 81/100 regulates the complex subject of worker safety in Italy. The first step in implementing safety is to assess the risk and implement the necessary interventions for its reduction or elimination [2] When the risk cannot be eliminated by measures of a general nature of risk prevention, such as the replacement of dangerous agents with others, or, by the reorganization of work procedures and methods, the legislation stipulates that the employer must provide the employee with appropriate Personal Protective Equipment (PPE), which reduces the risk to an acceptable level. The employee is obliged to use the PPE properly, take care of it, and, in some specific cases, undergo training and education before being allowed to wear and use it [3] On the other hand, the employer and safety officers must supervise the proper use of PPE. In fact, the provision by the employer of PPE, according to the regulations, does not exempt the employer from liability in the event of an injury occurring to the worker if he/she has not supervised the effective use by employees of the same PPE made available. Therefore, safety management requires large investments to implement effective supervision, which can only be provided by a large number of safety officers and cannot exclude human error. Added to these costs are those related to compulsory insurance managed by the INAIL, which all companies operating in Italy must pay and whose value is determined as a percentage of the worker's salary multiplied by a risk factor that depends on the specific task. Therefore, for companies, safety costs often affect turnover substantially by reducing their profits and are perceived as unnecessary. Unfortunately, in the presence of rapacious and unscrupulous entrepreneurship, those costs would gladly be avoided. The current regulatory system, based primarily on punishing noncompliance with safety requirements, seems to be an insufficient deterrent to stop the rampant spread of workplace accidents since companies find it convenient to economize on safety. Therefore, aware of the difficulties and limitations related to the current regulation and management of sanctions/penalties, the legislature recently has been moving toward a virtuous approach to occupational safety and health, in which the demonstration of the application of correct practices in the field constitutes a figure of merit for the company that implements them. INAIL's goal is to address the problem by pushing companies to invest more in prevention, introducing incentives and substantial discounts on insurance costs for companies that carry out concrete preventive actions, thus giving value to safety. The incentive mechanism also aims to compensate for the gradual reduction in the number of inspections, as a result of the reduction in the staffing of the bodies in charge of inspections; this is the result of recent policies to rationalize spending, which has led to a drastic reduction in the possibility of detecting and correcting behaviours that pose a risk to workers' health in time. The problem is how it can be measured and thus quantified the level of occupational safety that the company achieves and makes it eligible for economic incentives; thus, a new demand arises, the measurement of safety. The authors have tried to fulfil the requirement by proposing an innovative tool that leverages the new enabling technologies of the Internet of Things (IoT) ([4]-[17]) and Blockchain to ([18]-[21]) (i) record safety-related events in Blockchain in an immutable and transparent way, quantifying the level of achieved safety; (ii) enhance safety by transforming positive events recorded in Blockchain (correct use of PPEs) into "safety credits," i.e., electronic money that can be spent to directly pay insurance premiums/taxes to public administration and incentivize workers. More specifically, the authors set up a system consisting of PPE capable of wireless identification (RFID) ([22]-[23]) and an automated surveillance agent capable of recording operations and issuing consents in accordance with one or more rules set forth in the Risk Assessment Document (DVR) and encoded in a Smart Contract. The number of events and their magnitude recorded in Blockchain makes it possible to quantify the degree of achieved safety.

2. PROPOSED SYSTEM MODEL

The supervision owed by employers, managers, and safety officers does not have to be uninterrupted and with the constant physical presence of the supervisor next to the worker, but it can also be carried out discreetly. What is the important thing is its effectiveness in verifying that workers follow safety regulations and use the prescribed PPE. The employer's obligation to supervise is further mitigated when the worker is specialized and has a thorough knowledge of his or her task because he or she has been performing it for a long time. So, in the proposed model, verification of compliance with safety requirements is done automatically through the use of PPE with wireless communication capabilities due to the integration of an appropriate Radio-Frequency Identification (RFID) tag in each of them.

RFID is a technology that enables the remote recognition of an object by means of radio communications. In recent years the most popular automatic identification technologies have been barcodes and magnetic stripe cards; however, in the coming years, RFID may surpass them as it offers more complex functionality. Basically, the object to be recognized is coupled with a transponder (Tag) capable of communicating via radio the information required by a special Reader. Each Tag can be uniquely identified by a code stored in its microchip. The Tag can take any desired shape, can be exposed to the weather, or be coated with the material most suitable for the intended use of the object to which it is applied. A Tag can also store a substantial amount of data and allow real-time read and write operations from a distance of several meters. The fact that a Tag can be read at greater distances than a bar code or magnetic card is an inherent superiority of RFID systems over those technologies. An RFID system can be used to allow access to a given area, such as a construction site, only to personnel wearing the prescribed PPE. As for the proposed system, RFID tags are integrated into the PPE; by placing a Reader at the entrance of the area of interest, access is possible only to those individuals who present full compliance with PPE. Given the versatility of RFID systems, it is possible for each PPE to have a unique identification code, allowing it to be associated exclusively with a single owner. In this case, it is possible to know instant by instant who is inside a specific area and whether they are wearing the intended PPE. Some dangerous work devices (equipped with a Reader) can be made non-activatable if the operator does not have particular authorizations and/or is not wearing specific PPE, and verification can be done by the RFID management system (by means of the activation of an appropriate application) on the basis that the PPE worn (equipped with a unique Tag) is exclusive to a specific operator [24].

The second key element of the proposed system is the Blockchain, used for the permanent memorization of the events, registered by the RFID readers, and for the management of the reward mechanism. The combination of cutting-edge enabling technologies is the true innovation and the technological improvement of the proposed solution. It is proposed the use of a cryptocurrency to give birth to a new way of sharing value, consisting of security operations, exploiting the gamification logics. Practically speaking, the incentives follow the typical elements of games, even if in a not-ludic context; moreover, the used cryptocurrency doesn’t own a real economic value: first of all, it represents a piece of digital information stored within Blockchain infrastructure. The utility of the Blockchain system for the implementation of these functionalities stands in the characteristic transparency of the distributed transactions of the rewards assigned to the employees. Practically speaking, from the functional point of view, in the proposed model every employee is a user of the Blockchain, with an associated digital wallet where cryptocurrencies (or tokens) are received (as result of reward for a righteous behaviour) and stored. The events, recorded by the RFID readers, are sent to the Blockchain system through the invocation of a Smart Contract, that is a new form of contract entirely digital, used to automate the execution of an agreement and characterized by the absence of intermediaries. The contract is initially distributed through the network by means of a transaction, validated and approved by the Miners (that are system nodes) via a specific consensus mechanism (Proof-of-Work). When the Smart Contract is invoked, it stores permanently and immutably the information regarding the revealed events, and it rewards the employee in case of positive event (the correct use of PPE), crediting a token on the employee's wallet. Hence, every token on a wallet represents a positive event recorded on the Blockchain. It follows that, through this mechanism of rewarding, every worker is more motivated and stimulated to operate always respecting the security prescriptions: in fact, after a while the employee can accumulate a certain number of tokens convertible to salary increase, meal vouchers, fuel voucher, and so on. On its side, the company can use the total amount of cumulated tokens to certify the good security practices in the considered period and obtain discounts in the insurance payments to the INAIL. The final goal is, on one side to protect workers life and well-being, and on the other to allow general savings for both companies and INAIL.

3. DESIGN AND DEVELOPMENT OF A PROTOTYPE OF PROPOSED MODEL

In order to prove its feasibility and effectiveness, the proposed model was implemented in prototype form and applied in different working contexts. In particular, its two main modules were developed: (i) the hardware/software consisting of the antennas, the Reader for tag identification, and the management system; (ii) the Blockchain for measurement safety and enhancement.

Then, depending on the specific application, the planned PPE was equipped with suitable RFID tags from time to time. The solution was tested both in the laboratory and in the field. Figure 1 shows, for example, the simplest configuration of the system, consisting of a single RFID antenna, with which it is verified whether the operator is wearing an FFP2 anti-COVID-19 mask that has been equipped with an RFID tag, as required by the laboratory rules.

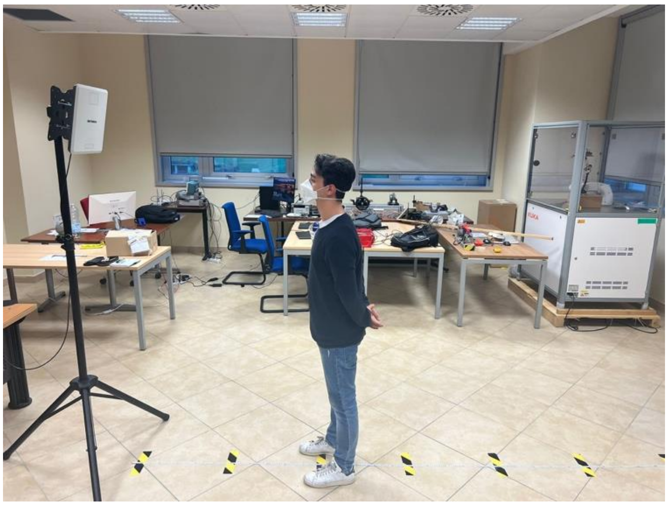

Figure 1. The simplest configuration of the system, consisting of a single RFID antenna.

3.1. PPE equipped with RFID tag

Once the decision to use RFID technology has been made and the formal specification of the intended purposes is known, the choice of tag type and system to be used can be made. Indeed, a number of parameters must be evaluated. First, the frequency-dependent transmission standard must be chosen:

- 125/134 kHz (ISO11784/85) low frequency (LF);
- 13.56 MHz (ISO15693, ISO14443) high frequency (HF);
- 868/915 MHz (EPC) ultra-high frequency (UHF).

The first two frequency values are usually used in "near-field" conditions, that is, they take advantage of inductive coupling. On the contrary, for the higher frequency UHF, applications are typically "far field," i.e., the effects of the electromagnetic field are dominant. Low-frequency (LF) RFID tags are characterized by a limited read range (in the order of tens of cm) but are a reliable solution for wet and metallic environments; they find, in fact, application in harsh industrial conditions as well as for livestock monitoring (Bolus RFID Tag). Tags operating at high frequency (HF) also have a short read distance (1.2 m maximum) and are negatively affected by metallic environments; however, differently from LF tags, they are rather insensitive to moisture and water. Smartphones with Near Field Communication (NFC) interface can be used as a Reader for HF tags, and they are widely used for ticketing and digital payment applications. Ultra-high frequency (UHF) tags are characterized by a read range of up to 12 m and a very high transfer rate.

Besides their operating frequency, Tags are classified according to their power supply into passive, semi-passive, and active.

- *Passive Tags* harvest the energy to power their internal circuits from the signal coming from the Reader. Once decoded the Reader signal, the Tag responds by reflecting and reshaping the incident field. Passive Tags are typically low-cost, small devices that enable many types of applications, which are often possible precisely because of the small size of the Tags. In fact, since they consist only of an antenna (typically printed) and an integrated circuit (usually miniaturized), the size of passive Tags can be very small (Figure 2). Therefore, such Tags can be inserted into credit cards, adhesive labels, buttons, small plastic objects, sheets of paper, banknotes, and tickets, resulting in talking objects.
- *Semi-passive Tags* have a battery used to power the control logic, memory, and any auxiliary equipment, but not the transmitter, behaving in transmission as passive Tags, which allows for increased battery life and, consequently, device life.
- *Active Tags* are battery-powered and can have very complex functionality, limited only by battery life.

The information that the Tag transmits to the Reader is contained in a certain amount of memory that each Tag contains within itself. The identifying information is related to the object being queried and usually consists of the unique serial number, or additional information (e.g., production dates, the composition of the object).

Figure 2. PPE with FFP2 filtering capacity equipped with an integrated RFID tag.

Then there are many other factors that affect the performance of an RFID system. For example, when an RFID tag is small, the reading distance is reduced; the speed at which the tags pass the reading device can also affect the resulting detection and reading. In addition, the mutual positioning of the tag and the RFID Reader affects the maximum read distance.

Given the technical features, the low cost of the tags, the coverage ranges that allow freedom of movement for workers, and the fact that the tag can be coated with the most suitable material for the intended use, passive tags and systems operating at UHF frequencies are the most suitable to be coupled/integrated with/in PPE and used for workplace safety applications [25]. One of the PPE considered during the research activity is a respiratory protection PPE with FFP2 filtering capacity equipped with an integrated RFID tag. The tag is placed laterally under the outermost layer of the face mask as shown in Figure 2.

3.2. Antenna, Reader and Management System

The Reader is a microprocessor-controlled transceiver used to interrogate Tags and receive in response the information they contain. To interrogate the tags, the Reader takes advantage of antennas, which in the case of passive tags provide the energy necessary for the tag to power its circuits and respond by reshaping the incident field. In addition to the Reader, a management system is required, networked with the Reader, which allows, from the identification codes coming from the Tags, to derive all available information associated with these objects and manage it for the purposes of the application.

The choice of operating frequency and the maximum value of power radiated by the Reader affect the operating distance of the system, interference with other radio systems, data transfer rate, and antenna size. In particular, the power limit of RFID antennas is generally expressed in terms of effective radiated power (ERP) in watts. However, power can also be expressed in decibel-milliwatts (dBm), which is a measure of power in decibels relative to a milliwatt reference power. For example, if the transmission ERP power limit of the RFID antenna is 2 W in Europe, the corresponding power values expressed in dBm would be:

$$P_{\mathrm{dBm}} = 10 \cdot \log_{10}\left(\frac{2\ \mathrm{W}}{1\ \mathrm{mW}} = 33\ \mathrm{dBm}\right). \quad (1)$$

The higher the radiated power, the greater the distance at which the tag can be read and thus the presence of the PPE identified ([26]-[29]). In this research activity, characterization tests were performed at 30 dBm, 27 dBm, and 24 dBm. Therefore, a reader model KATHREIN RRU 1400, which can simultaneously handle up to 4 antennas and is equipped with an Ethernet port to be connected to the enterprise network, was used for prototype development. The KATHREIN model WRA 6060 was used as the antenna [30].

3.3. Blockchain development for safety enhancement

The Blockchain has been created exploiting the Ethereum technology, that allows to both use digital money and execute Smart Contracts. Unlike contracts used in the real world, Smart Contracts are cryptographic coded software, executed on the Blockchain, and they are used to automate the execution of an agreement with no intermediaries involved. The Smart Contracts are coded to follow a "if-then" logic: that is, "if certain conditions are verified, then a specific operation is executed". In the application depicted, the Smart Contract has been implemented with Solidity Programming Language; when the management system notifies the correct use of a PPE, the Smart Contract carries out an economic transaction, sending a token to the wallet of the employee involved, that earns a digital credit. From the software point of view, the Smart Contract is a Solidity class, made of constructor, variables, and member methods. In particular, when the positive event occurs the Smart Contract's method *callContract* is invoked [31]-[32] and it performs:

- Immutable memorization of the information related to the event (tag identifiers, time, employee's ID and wallet, etc.);
- Check of the Boolean variable *PPEcheck* set by the management system, that is true if the PPE is correctly worn and false otherwise; if the value of such variable is true, the *transfer* function is executed, crediting a token in employee's wallet.

The implemented Ethereum network consists of a node performing the mining activities, with the aim to validate the transactions, add the approved ones to the Blockchain, and generate the tokens distributed to the employees. The number of owned tokens by each employee gives a measure of its virtuous behaviour, while the total amount of tokens owned by the whole company workforce gives a synthetic index of the gained overall security level: the "measure of security".

Figure 3 shows a portion of the Smart Contract code written in the Solidity language [33]; while Figure 4 shows the wallet of an employee in the MetaMask environment, who earned 1 ETH as a result of the recognition of a positive event.

4. APPLICATION OF THE PROPOSED SYSTEM TO ENHANCE WORKPLACE SAFETY IN DAIRY FARM: A USE CASE

In livestock farms, a typical worker works in close contact with animals that can cause mechanical and biological damage. In particular, it is necessary to prevent the spread of zoonoses, that is, diseases transmitted from animals to livestock workers. To give an idea about the importance of the problem, it is enough to recall that the pandemic caused by COVID-19 is a zoonosis

```
function callContract(Employee calldata _employee, bool _PPEcheck) external returns (string memory){

    settingParameters(_employee, _PPEcheck);
    string memory messageOutput = checkAndSendEther();
    return messageOutput;

} /* end callContract */

function checkAndSendEther() public returns (string memory)  {

    string memory message = "";

    if(PPEcheck == true) {
        payable(getEmployee().employeeWallet).transfer(1000000000000000000);
        message = "PPE worn correctly!";
    } else {
        message = "PPE not worn correctly!";
    }
    return message;
} /* end checkAndSendEther */


} /* end contract */
```

Figure 3. Portion of the Smart Contract code written in the Solidity language.

[34]; one of the many infectious diseases of animal origin that have infected humans in recent years, making the infamous species jump. Population growth, urbanization, increasing wealth in middle-income countries, and related changes in diet, including a growing demand for animal products, are driving further agricultural expansion and changes in farming patterns, often at the expense of natural ecosystems.

Large numbers of animals (often immunocompromised, with low genetic diversity, and in poor condition-live on intensive farms) are constantly in close contact with one another, making them vulnerable to the emergence and spread of epidemics. The only way to stem the risk of new spillovers, and thus new regional or global health emergencies, is prevention. Various infectious diseases are then widespread on buffalo farms, some of them particularly dangerous because they are transmissible to humans, i.e., tuberculosis (TB); Brucellosis; Salmonellosis.

The risk of contracting direct zoonosis is very high for animal handlers, given the frequent contact with the animal, its secretions and the environment potentially contaminated by them. This risk is increased due to the low perception of the utility of adopting protective equipment; moreover, workers are often not properly and adequately trained for PPE exploitation. Many processes performed within livestock farms must be carried out, in whole or in part, wearing personal protective equipment in order to reduce any residual risks present in the various work phases. It follows, therefore, that all appropriate

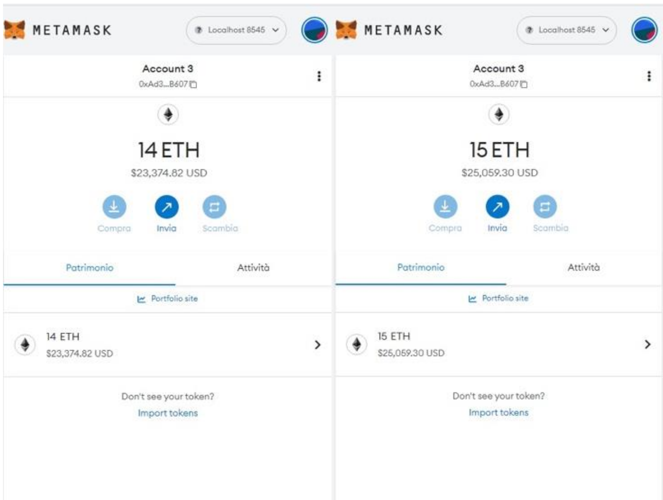

Figure 4. Wallet of an employee in the MetaMask environment, who earned 1 ETH as a result of the recognition of a positive event.

PPE must be present on the farm to protect the worker in the various work phases.

In particular, as far as buffalo farms are concerned, the following PPE has to be equipped according to specific risk:

- moisture: boots, waterproof clothing, waterproof gloves, etc.;
- soiling materials, such as droppings: boots, waterproof clothing, gloves, etc.;
- falling materials and crushing safety shoes and hard hat.

Other PPE should be made available and used only in special situations:

- filtering facemasks (FFP2/FFP3) and protective goggles (for situations where there is dust uplift/movement, when giving birth and fertilizing animals);
- gas facemasks or possible self-contained breathing apparatus (in case of accessing and staying in typically enclosed places where toxic gases or vapours can be developed and accumulated in high concentration and in handling emergency situations).

Therefore, the system proposed by the authors, based on an intelligent combination of IoT and Blockchain technologies for measuring and improving workplace safety, can also be effectively applied to buffalo companies. In particular, a field trial was initiated at a buffalo company located in southern Italy, where the proposed system was adopted on an experimental basis. The objective of the experimentation is to verify, on the one hand, the performance of the system in the working environment (in terms of its effectiveness in recognizing the PPE sensorized with tags as operating conditions change), and on the other hand, to evaluate the safety improvement achieved in the company thanks to its adoption.

5. CONCLUSIONS AND FUTURE PERSPECTIVE

The preliminary results obtained demonstrate that the proposed method is both feasible and effective. To test the system, a barn with 60 animals equipped with an automatic milking system was selected as the test area within the farm. Each farm employee enabled to access the test area was provided with a set of four PPEs (FFP2 mask, gloves, boots, and glasses), which were equipped with RFID tags for identification purposes. The employees used the PPEs according to the risk assessment document, depending on the operation they were performing. To evaluate the system's performance, a reader with an antenna was mounted at the barn access gate at a height of 1.5 m from

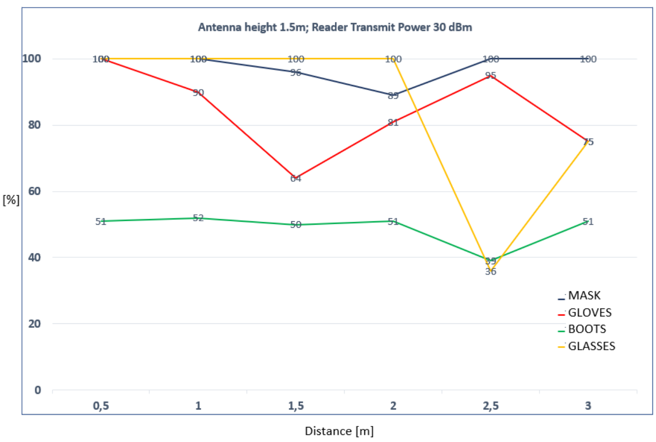

Figure 5. Performance of the system in the working environment.

the ground, and with a transmission power of 30 dBm. An initial characterization was carried out, and the results are shown in the graph (Figure 5). The reader was able to detect the presence of all PPEs with good reliability up to a distance of 3 m from the antenna. The worst performance was obtained for boots, which may be due to the fact that they are in the most unfavourable condition compared to the antenna radiation pattern when worn. However, even at a distance of 3 m, the success rate of boots identification remains above 50 %, making it still possible to identify their presence at an acceptable time for application. For FFP2 masks and goggles, success rates close to 100 % were obtained up to 2 m. However, for gloves, the success rate of readings decreased from 100 % at 0.5 m to 64 % at 1.5 m, emphasizing the importance of the mutual position between RFID tag and antenna. In terms of using blockchain for safety measurement and improvement, there is a gradual increase in successful events, but more data are required for an overall evaluation, including a survey that will be administered to users at the end of the trial.

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