Engineering World Health Design Competition 2020

KeepTrack

A blockchain driven communication tool

University College Dublin Centre for Biomedical Engineering

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1. Problem definition

Medical equipment is a fundamental part of modern healthcare delivery [1]. Advances in medical device technology have improved health care systems around the world and allowed patients to receive better care. However, low and middle-income countries (LMICs) often have limited access to this medical equipment and it has been estimated that up to 80% of all medical equipment that is utilised in these regions has been donated [2]. Although there are many well-intentioned donors, low adherence to published guidelines is common. Poorly planned and executed medical equipment donations will not deliver on desired outcomes and often unnecessarily burden healthcare systems in the form of indirect costs [3].

For example, an estimated 40% of medical equipment donations are out of service [2]. Local technician expertise can be sparse and the supply chains to get replacement parts are few and often have long delays [4]. Even with the correct supplies, service manuals are often missing, not in the local language or not shared by manufacturers for intellectual property reasons or due to the device being discontinued [5]. In the case that the equipment does arrive in a functional state, it still may not be useful. In many cases the donations are not compatible with the local electric power supply or the machine may not come with the additional consumables it needs to function correctly [6].

Recipients may be reluctant to point out the futility of donor efforts to avoid appearing unappreciative of the donation effort and currently don't get ample opportunity to offer feedback [7]. As a result, 'medical equipment graveyards' of obsolete or broken donated biomedical equipment are commonly seen in health care facilities across LMICs which take up essential space often becoming a health hazard as corridors and public areas become crowded with equipment.

By conducting a thorough literature analysis and interviewing over five stakeholders with roles in different stages of the donation supply chain, the importance of improving communication and transparency between donor and recipient was noted as an area requiring significant improvement with the potential to substantially improve the efficiency and efficacy of the entire donation effort.

Our system, called KeepTrack is a blockchain driven mobile application (app) which has a database that can be updated both online and offline. The system interfaces with RFID tags which will be attached to donated equipment by donors.

Using the app a healthcare worker/BMET could scan the unique tag to retrieve important device information such as the make and model of the device, where to source the user manual, the previous date that the device was serviced, when the next maintenance is due, operational status of the device, contact details of manufacturer/ local technician if the device needs repair, information regarding how the device should be disposed of, a section for feedback and an area where medical equipment needs can be updated.

The main challenges we address with our solution are a lack of understanding between donor and recipient, insufficient support for the long-term integration of equipment and a lack of data on the global donation system [1].

2. Statement of Impact in Developing World

The current system of medical equipment donation is fragmented involving multiple stakeholder groups who have a limited understanding of each other's roles and activities. This leads to confusion, duplication of effort, and recipients getting unwanted or incompatible medical equipment. Through our blockchain-driven app, we aim to bring together various stakeholders in the medical equipment donation ecosystem.

Since 1980, 33 biomedical equipment donation guidelines have been published by governments, WHO, World Bank, academic colleges and non-governmental organisations [3] and yet compliance remains low which demonstrates the need for better transparency and accountability along the donation supply chain. The impact of KeepTrack will be manifested in the form of cost savings, greater transparency through data collection and an improved relationship between the donor and recipient. Our app helps to make donations more efficient, reducing the amount of inappropriate donations which have hidden costs for the recipient. A Tropical Health & Education Trust (THET) report states that the appropriate selection of medical equipment could result in savings of up to 90% on the operational and maintenance cost over the lifetime of the equipment [8].

Donated equipment that is functional has associated costs in the form of maintenance and staff training. It has been estimated that these additional costs amount to 10% of the purchase price, per year of operation [8]. Our app increases accountability from donors and encourages the inclusion of service maintenance packages to reduce this cost. The increased efficacy of donations will reduce additions to 'equipment graveyards' saving space and staff time.

In our research we spoke with six individuals who work (or have previously worked) in an LMIC healthcare facility to gain insights on how equipment repair is carried out. Generally we found that if the facility has onsite equipment personnel, they generally keep track of the equipment themselves and do not use logging tools. Due to time pressure and limited resources they tend to rely on their memory rather than an equipment inventory. This system tends to break down when the technicians are not working full-time at the facility or a new equipment maintenance worker begins as they have to learn where equipment and relevant parts are located which takes up staff time.

An updated and user-friendly inventory reduces reliance on a technician's memory and allows for convenient handover. Having easy access to information about the device and service maintenance contract details allows the equipment personnel to carry out necessary repairs more efficiently.

As countries begin to evaluate their health systems in reaction to the United Nations Sustainable Development Goals the lack of data surrounding the efficacy of medical equipment donation has become clear [9]. The WHO have begun to conduct surveys on the donation of medical equipment in an effort to gather crucial data related to the global medical equipment donation system [1]. The data collected from our app would provide transparency on the eventual use of donations and their level of benefit. Our system empowers recipients to give feedback on donated equipment using a safe platform.

Data is beneficial to donors as many large medical equipment and pharmaceutical companies are set to increase their market share in these LMICs over the upcoming years [10]. KeepTrack empowers communication between parties to help create a future with more sustainable donations.

3. Required performance specifications

To ensure adequate uptake of our solution by medical professionals in both recipient and donor hospitals/organisations, it is necessary that our solution is:

- User-friendly
- Capable of interacting with a database of stored information
- Data can be transmitted quickly even with low-bandwidth

Through our research, it became apparent that biomedical technicians on the ground are reluctant to adapt to new systems due to the added time required to adopt and integrate a new system. To ensure the success of our solution, it is therefore essential that the app is intuitive to interact with, thus requiring no/limited training, and provides significant benefits to biomedical technicians attempting to repair equipment in challenging circumstances [11].

The application should be compatible with varying hardware and software architecture (eg. compatible with 32-bit systems, a variety of open-source operating systems and earlier versions of mainstream operating systems).

Through the implementation of blockchain technology and due to the nature of this technology, the database should be:

- **Immutable**: Once information is uploaded, it cannot be deleted, tampered with or lost. Blockhains get this property from utilising the cryptographic hash function. Blockchain technology uses cryptocurrencies which are immune to counterfeiting.
- **Transparent**: The application should allow two way communication between donor and recipient. Recipients should be able to specify their needs (e.g. equipment needed, type and number of procedures expected to be performed using the equipment), and limitations (e.g. power supply specifications, expertise). Donors should be able to provide information about the device and identify potential recipients and ensure that they have the resources and expertise required to install, operate and maintain the equipment. The application should facilitate development of a suitable donation plan and provide a follow-up evaluation of the donation process [1]. Through blockchain, when you make a transaction, your real identity is secure. However, your public address and the transaction you made can be seen by anyone. This would allow traceability along the donation chain.
- **Decentralized**: A decentralized network is a “trustless environment,” where there is no single point of failure. The nodes connected in the network are not dependent on a single server point and each node holds the entire copy of the network configurations.

4. Implementation of prototype

4.1 Application

Our app prototype was developed using the Python programming language, using Kivy - a free and open source Python library for developing mobile apps with a natural user interface. We chose to develop our interface using Kivy due to it's cross platform capabilities which can eventually allow launching on both android and Apple devices, should the need arise. Android apps can also be utilised on Raspberry Pis.

Our app was developed to cater for both donor and recipient health care facilities, and this functionality is reflected in the design. Upon launching the app the user is prompted to login, if the details they have entered match a registered hospital in our database, they are permitted entry, and if not they are alerted to the fact their login is invalid, this can be seen in the schematic in **Appendix A1**. Having confirmed their identity, the app is then subdivided into two separate categories - either donor or recipient. We chose this layout, as we wanted to enable individual hospitals to act as both donors and recipients, such that even though a hospital is in need of certain equipment, it does not prevent them from donating other superfluous machines from their hospital.

If the purpose of this visit to the app is to donate equipment/view previous donations the user would select 'Donor' and the flow of the app proceeds as per the schematic detailed in **Appendix A2.**If however, the user would like to request a donation/view available equipment/scan the RFID tag of a machine requiring repair to locate the user manual or other useful information, the user selects 'Recipient' and the flow of control of the app proceeds as outlined in **Appendix A3.**

The database functionality was added to our app using the Python 3 SQLite library, which allows the user to interact with certain information stored in the database. Our database consists of five tables, namely: User, Recip_Req, Login, Donation, Available_Equipment. The information stored in these tables are manipulated as a result of user entries and form the foundation of our app. The information stored in these databases can be viewed using the DB Browser Application to facilitate administrative control for the developers. The details stored in each database and the database as seen in the DB Browser for SQLite are shown in **Appendix B.**

All code related to the project can be downloaded from the GitHub repository at https://github.com/emmabailey-uni/EWH_Kivy.git. To run the app for development on your own computer, it is necessary to have Python, Kivy and Numpy installed.

4.2 Blockchain

The blockchain structure currently consists of:

- Request ID (shown in **Appendix C1)**
- Request message/ task containing details of equipment requested, quantity and hospital name. (shown in **Appendix C2 and C3)**
- Whether the requested donation has been accepted/completed. (shown in **Appendix C4)**

The current prototype of the app with blockchain implementation accepts users' request for donations and agreement to fulfil donation requests. The other elements that need to be incorporated into a future blockchain element according to the donation requesting and matching pages of our app can be seen in **Appendix C5.** The layout of the blockchain node structure can be seen in **Appendix C6.** The smart contract will have the following functions: request_donation, accept_donation_request, new_machine_donate and are called depending on the user inputs from the app front end.

Function request_donation is called when the user selects the option to request donations from the app front end. It will initialize a new node with default values and updated ID and is added at the end of the blockchain and set donation request or adding donation (req_or_don) as True (corresponding to request) and prompts the user to enter details of donation request (see **Appendix C7**)It then sets Donation request accepted or not (req_accept) as False prior to any donor accepting request for donation**.** The donation request can be seen on selecting the view donation requests options in the main menu (See **Appendix C8**)**.**

The function accept_donation_request will be called when the user accepts a donation request for a particular machine. The function matches it to the blockchain element ID and updates this information at the end of the blockchain and asks the user to enter the required information (See **Appendix C9**). When an accept_donation_request is called for a particular machine request, the Donation request (req_accept) is set to True for that ID (See **Appendix C10**)

Function new_machine_donate will be called when the user selects the option to add a new donation. The function will initialize a new node with default values and updated ID and adds this node to the end of the blockchain. It then sets Donation request or adding donation (req_or_don) as False (corresponding to donation) and prompts the user to enter required values (see **Appendix C11**). The Donation available node (don_avail) is set to True to indicate that the equipment is yet to be matched to a requesting hospital. See **Appendix C12.**

This version was tested on a personal blockchain platform provided by the truffle framework. The source code can be found at https://github.com/arlenejohn/equipment_donation

4.3 Hardware

An RFID tag scanning circuit was built using a 13.56M Hz RFID reader chip (similar to that found in smartphones) and a high frequency passive tag.This was implemented on both an Arduino MEGA 2650 model and a Raspberry Pi 2 model B .Circuit schematics can be found in **Appendix D**. Passive RFID tags can be read at a distance of up to 3 feet [12]. Due to ease of use, better CPU and faster RAM we envision our system being deployed with smartphones however, the app and tag scanning can also be implemented on Raspberry Pis.

5. Proof of performance

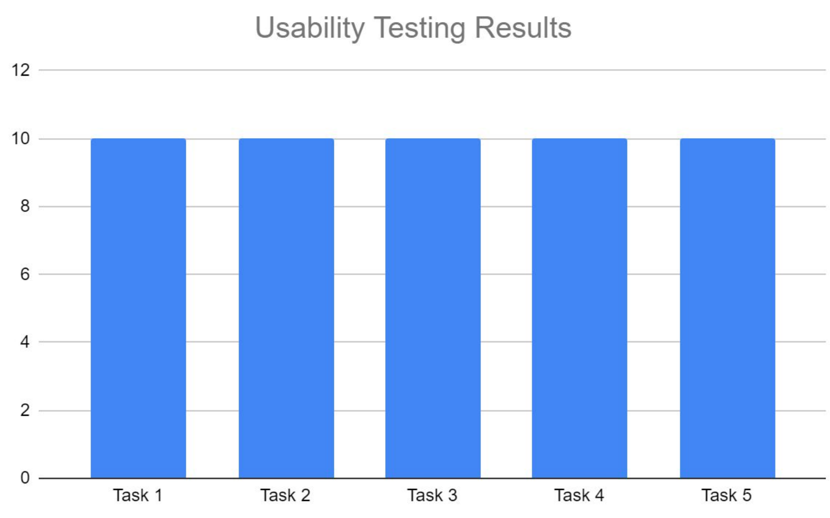
5.1 Application user testing

To prove that our app prototype met the required performance specifications (easy to use, capable of interacting with a database of stored information, fast reaction times) we conducted usability testing. We conducted our study in accordance with I.S. EN 62366:2009, and enlisted 10 volunteers to test our product. The volunteers ranged in age from 18 to 70 years and each participant received the same training and undertook the same tasks. The participants were allowed a maximum of a 30 minute training session with a member of the development team - during this time they were allowed to examine the control of flow diagrams seen in **Appendix A1, A2 and A3.** Having analysed the schematics, they were allowed to ask any questions of their trainer and given login details for the application.

To test our product we devised five tasks for the volunteers to complete, and measured their performance based on the following criteria:

1. Did the participant successfully login using the provided details?
2. Can the participant act as a donor and navigate to the page to donate new equipment?
3. Can the participant act as a donor and navigate to view their previously donated equipment?
4. Can the participant act as a recipient and navigate to edit their profile?
5. Can the participant act as a recipient and navigate manually input a serial number/attempt to scan an RFID tag?

The results of our usability study concluded that our product is intuitive to use with minimal training, with the results of each task summarised in the chart below indicating a 100% success rate:



To verify the interaction of the application with the database, we developed several test cases in which different members of the team edited tables in the database through the use of the application, and we verified the details submitted matched those which were displayed when the database was subsequently viewed using the DB Browser. Further to this, the response of the app was monitored with a simple timer during these tasks, any interactions which took more than one second to process in the prototype environment were deemed insufficiently fast. With these criteria in place, there were no adverse responses reported during testing. These tests thus indicate we have achieved the goals we initially devised and we can confirm the app is easy to use, sufficiently interacts with the database and has quick response times

5.2 Proof of Immutability and transparency aspects of blockchain

The blockchain prototype is deployed on a personalized blockchain testing environment provided by the truffle framework and it can be used to view all the transaction blocks in the blockchain.

In **Appendix E1**, we can see the list of transactions associated with the blockchain, corresponding hash and date and time associated with that block. If a block is selected, details of that block can be viewed and is shown in **Appendix E2**. From the hash values, it can be observed that they are the same blocks. The event called being TaskCreated associated with adding a donation request, the request being “2 anesthesia machines, Kaduha Hospital, Rwanda.”

5.3 Hardware

To validate the feasibility of the RFID tagging system the reading chip and tag system was built using an Arduino Mega 2560 and a Raspberry Pi 2 model B as the control units.

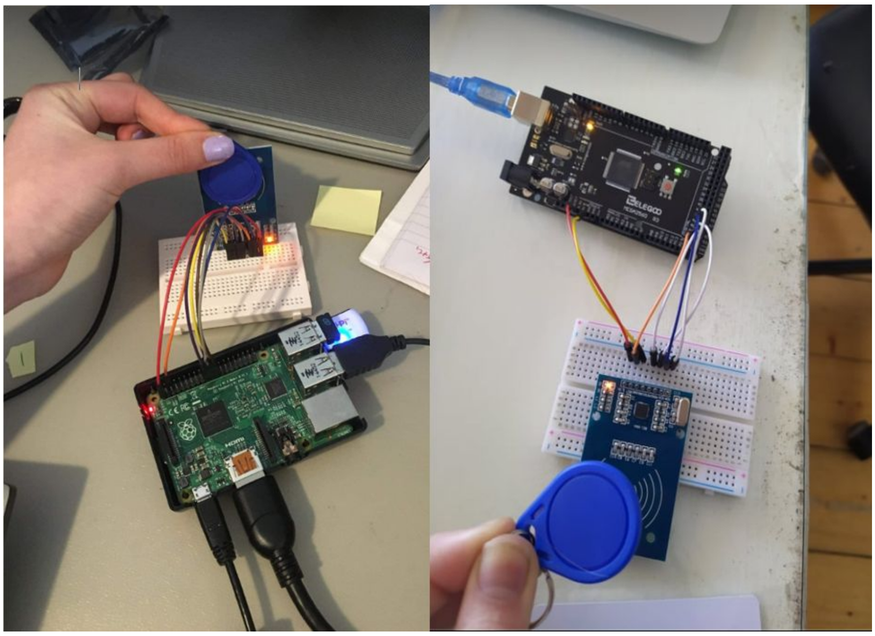


Image: proof of concept testing with Raspberry Pi and Arduino RFID tagging.

We utilised an RFID RC522 set for this experiment. Once both schematics were built three different scanning distances were tested with the tags (5cm, 10cm and 15cm) for ten trials. The time taken for the chip to scan the serial code was also recorded. At a distance of 5cm the system scanned the serial code of the tags with a 100% success rate and at an average time of 0.7 seconds. At 10cm distance the success rate dropped to 40% with an average time of 2.1 seconds and at 15cm no tags were scanned. Passive RFID tags are a suitable technology for this application as they require no power input, they’re compact and unlike barcodes they can be read at various angles.

6. Business plan for manufacture and distribution of the technology

The infrastructure around developing, deploying and maintaining KeepTrack will be set up as a not-for-profit organisation. The customers can be separated into two main constituents: medical device donors and recipients. Donors may include hospitals, clinics, NGOs, and private companies. Recipients may include hospitals and clinics in LMICs, NGOs and governments.The donor will pay a once-off fee per piece of equipment that will go towards the maintenance of the KeepTrack system. The price will adjust based on the value of the equipment donated and will be kept below 10% of the price of the equipment and service maintenance package. The donor will receive data insights on the impact of their donation and their public image will improve as they can show that they donated in an ethical and sustainable manner.

Once a donation has been agreed, RFID stickers will be distributed to donors and attached to the donated equipment prior to or during distribution. RFID tags will be purchased and shipped in bulk to our central distribution centre in Dublin, Ireland. There, they will be packaged with adhesive stickers and distributed to donors for device application. We will source our RFID tags from OPPIOT Technologies costing €0.23 per tag and our industrial vinyl stickers from SignSelect costing €0.30 per adhesive. These tags operate at 13.56MHz which makes them compatible with the NFC reader in mobile phones.The stickers are weather-resistant, chemical-resistant and have great mechanical flexibility so they can be applied on sharp edges or curved surfaces. Cost of shipping to donors is dependent on location, however, costs will likely be low due to the light weight and small size of the RFID tags and stickers.

After an initial investment of €100,000 to outsource the development of remaining features of the app and fund the pilot study, and assuming an increasing equipment volume each year, KeepTrack will be financially self-sufficient by year 3.

This will be funded through corporate sponsors, donations, and grant schemes from medical companies such as the Quality Improvement Grant from Pfizer or the Health Innovation Fund Ireland ([13] & [14]). With funding the app and tagging system will be developed and deployed within 6 months. The app will be free to download on the App Store and Google Play Store.

	Year 1	Year 2	Year 3	Year 4	Year 5
Investment	+€100,000				
Eq. volume	500	2000	2500	3500	4500
Revenue	**€5,000**	**€25,000**	**€40,000**	**€60,000**	**€70,000**
Total costs	€85,250	€26,100	€26,375	€52,200	€32,475
RFID tagging	€250	€1,100	€1,375	€2,200	2,475
Pilot study	€10,000	€0	€0	€0	€0
Staffing	€20,000	€20,000	€20,000	€20,000	€40,000
Software Development	€55,000	€0	€0	€25,000	€0
Software maintenance	€0	€5,000	€5,000	€5,000	€10,000

Image: Five year cost & revenue projection for KeepTrack.

Initially a cloud-stored database will be used as opposed to blockchain. This cloud database is initially cheaper and can be deployed rapidly. A public cloud is estimated to cost €0.14 per GB of data [15]. However, as the user base grows the value and benefit of using blockchain increases. We got the opportunity to speak with Joseph Thompson who was the CEO and Co-founder of AID:Tech which is a company that uses blockchain and digital identity to deliver digital entitlements including welfare, aid, remittance and donations. He alongside 2 other blockchain researchers (Dr. Paul Cuffe & Olakunle Alao) advised us on pricing, development times and the integration of blockchain with mobile applications.

With KeepTrack blockchain technology adoption is projected for integration in Year 4. The blockchain that is implemented with the app will be developed using the Ethereum platform. Since it is a small scale system in terms of transaction volume, the cost is estimated to fall around €5,000 - €30,000 [16] with maintenance costs of approximately €5,000 per annum.

The app is designed to function primarily with smartphones, but Raspberry Pi and Arduino technology will be compatible if needed. As the user-base grows internationally, some regions may have less access to phones and may instead benefit more from a donated Raspberry Pi or Arduino in order to use the app. It is adaptable to suit the needs of the users.

Dependable security and privacy is paramount for our users. Users will require a valid ID and password to access their account. Various security checks will be built into the app to prevent misuse of the system. We have researched many apps that are currently utilised within existing healthcare systems such as Epocrates, Medisafe and SEHA to ensure that our security features are in line with current industry standards [17], [18], [19].

After the development of our MVP we will run a pilot study. St Francis' Hospital in Katete Zambia expressed interest in trialing our system. This is a suitable location as the team has pre-established connections there, the hospital is heavily dependent on appropriate donations and there is widespread availability of phones and affordable internet access in the area.The pilot will help us to gain insights, feedback and make appropriate adjustments. Further development will involve Zambian NGOs such as *On Call Africa* and *Aid for Africa* acting as distribution channels. We will leverage the results of our pilot study to partner with Medical equipment NGOs and charities who will be the distribution channel for our technology.

Regarding regulatory compliance, the app does not have to be assessed in Zambia as it does not store any patient records. For most LMICs the app would not have to go through regulatory clearance as there is no patient data being stored [20]. As the app does not have to receive clearance the time to market will solely depend on development, making deployment much easier.

With KeepTrack we address the lack of understanding between donor and recipient, insufficient support for the long-term integration of equipment and an absence of data on the global donation system. Our solution is technologically feasible, can be easily deployed and has potential to grow and adapt alongside the needs of our users. At KeepTrack we are committed to empowering communication and increasing transparency along the donation chain.

7. References

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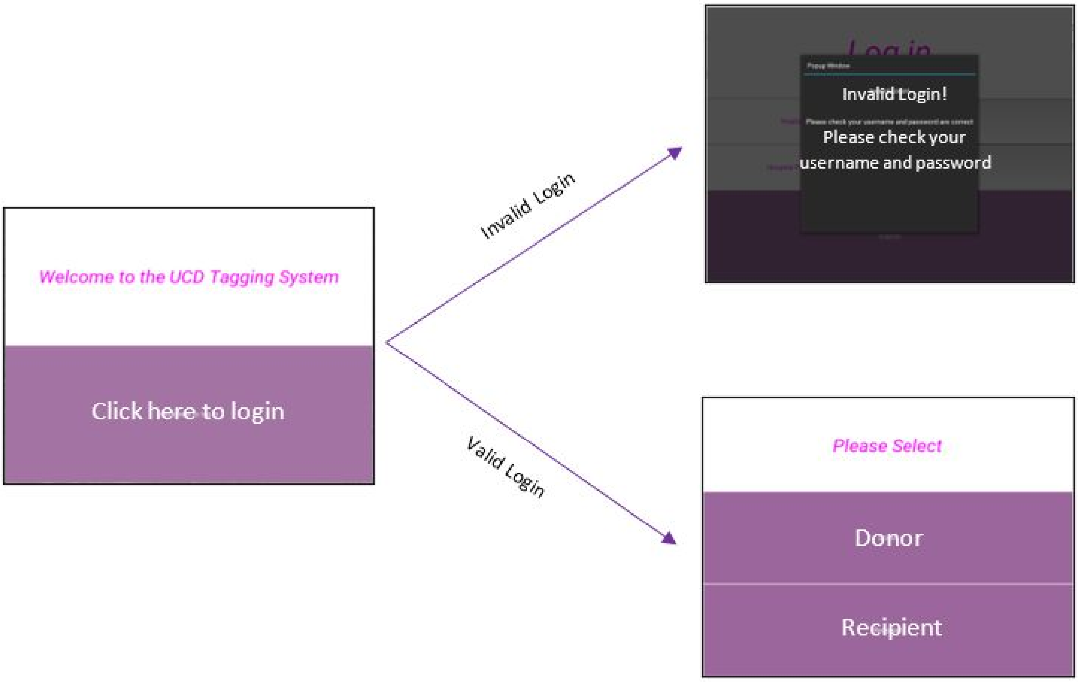
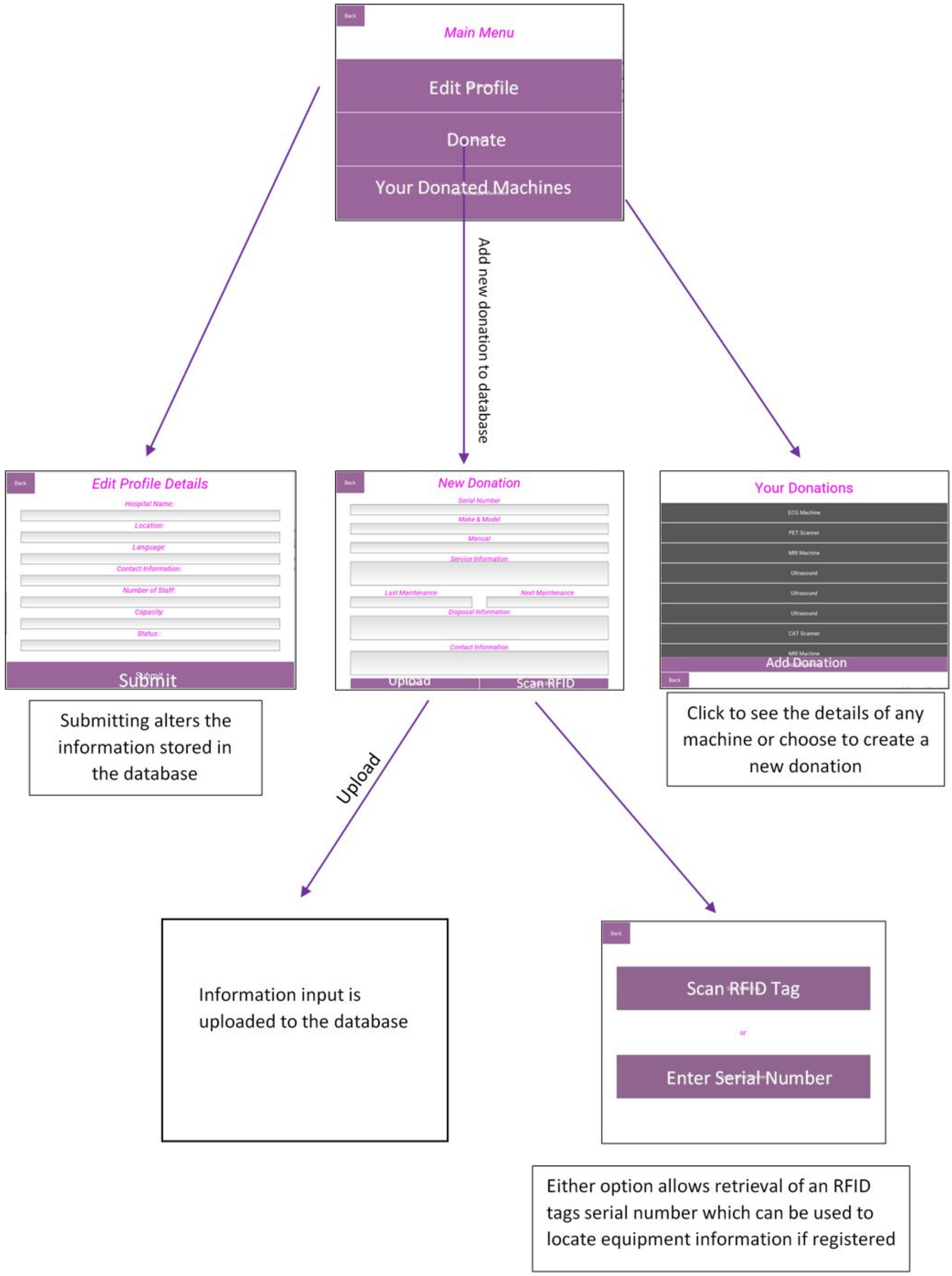
8. Appendix A - Application Flow of Control

Throughout Appendix A, text boxes have been added over certain elements where the text was deemed to be illegible.

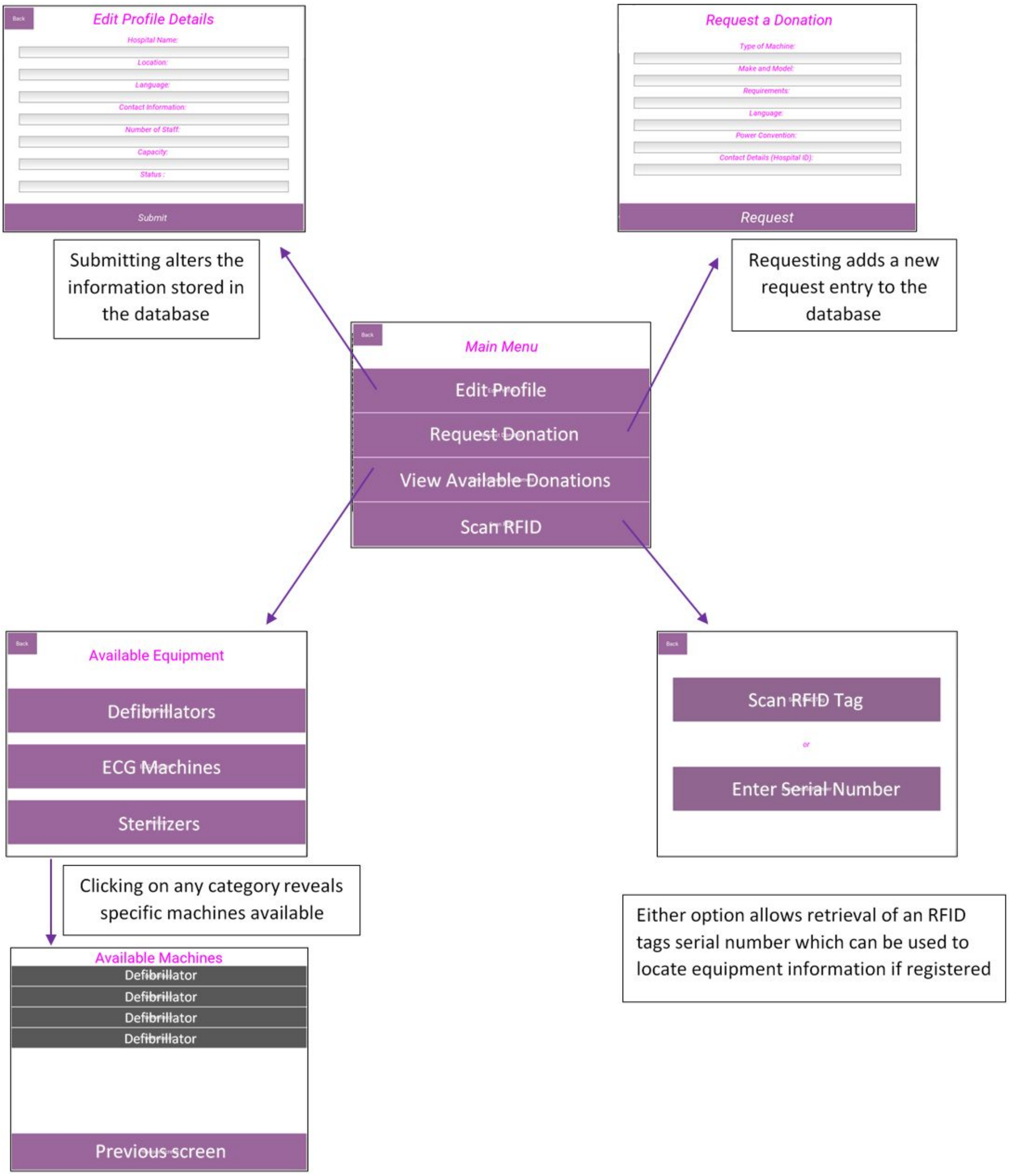
1 - Login protocol



2 - Donor Flow of Control

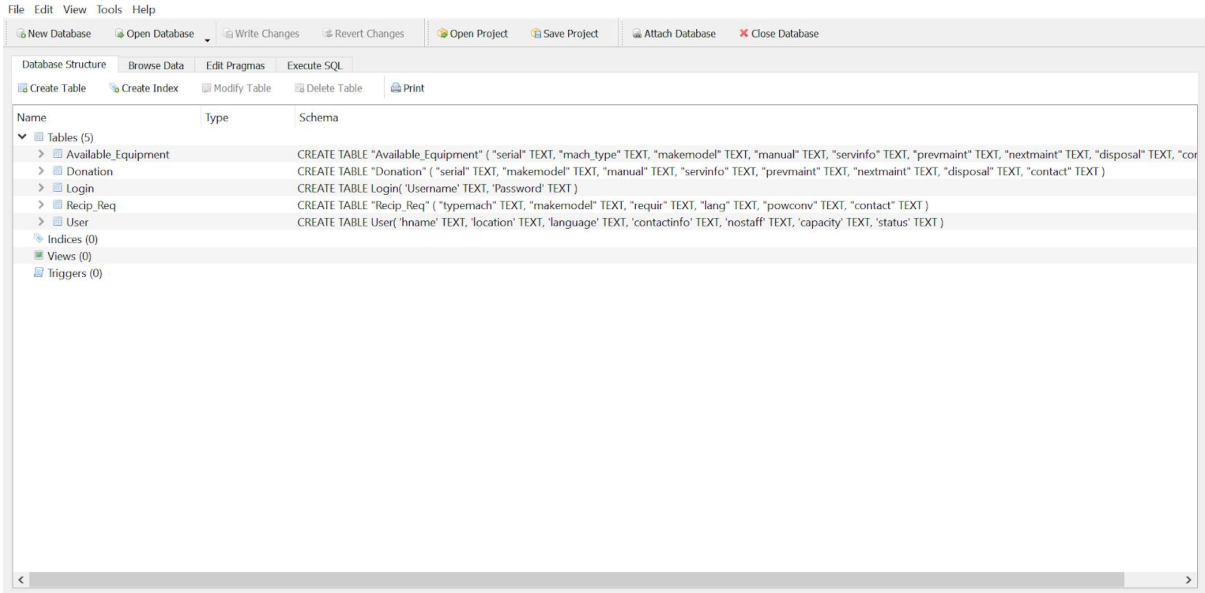


3 - Recipient Flow of Control



Appendix B - Database

Database as seen in the DB browser:



User:

This table contains information relating to the profiles of individual hospitals, information included is as follows:

- Hospital Name
- Location
- Language(s) spoken
- Capacity of the Hospital
- Status

When we registered our university as a hospital, the information is presented as follows

hname	location	language	contactinfo	nostaff	capacity	status
Filter	Filter	Filter	Filter	Filter	Filter	Filter
UCD	Dublin	English	ewhucd@gma...	20	2000	Donor

Recip_Req:

This table contains a log of equipment requested by hospitals ie. Donations needed. The information contained in this table is:

- Type of Machine Required
- Make and Model desired
- Specific Requirements
- Language(s) understood in hospital

- Power Convention
- Contact details for donor hospital

typemach	makemodel	requir	lang	powconv	contact
Filter	Filter	Filter	Filter	Filter	Filter

Login:

This table contains the hospital usernames and passwords required to gain entry to the app. When a login is attempted, the details are cross checked with the database to ensure the hospital has been registered.

Username	Password
Filter	Filter
UCD	UCD2019

Donation:

This table contains information regarding donations that have been made by donor hospitals/organisations. The information contained within includes:

- Serial Number on RFID linked to machine
- Make and model of machine
- User manual for machine
- Relevant service information
- Previous maintenance
- Next scheduled maintenance
- Relevant disposal information
- Contact information for the donor

serial	makemodel	manual	servinfo	prevmaint	nextmaint	disposal	contact
Filter	Filter	Filter	Filter	Filter	Filter	Filter	Filter

Available Equipment:

This table contains the information related to donated equipment that has not been matched to a recipient hospital and is available for selection. The information presented to potential recipients is as follows:

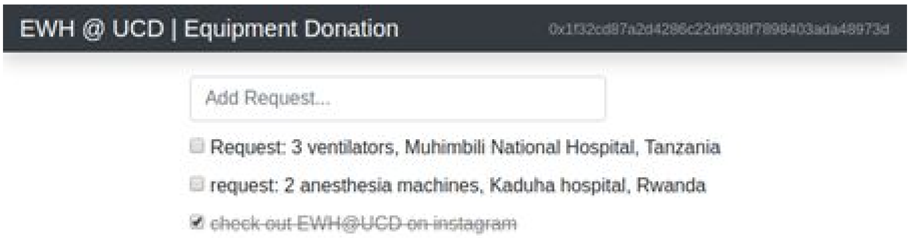
- Serial Number on the RFID linked to the machine
- Make and model of machine
- User manual for machine
- Relevant service information
- Previous maintenance
- Next scheduled maintenance
- Relevant disposal information

- Contact information for the donor

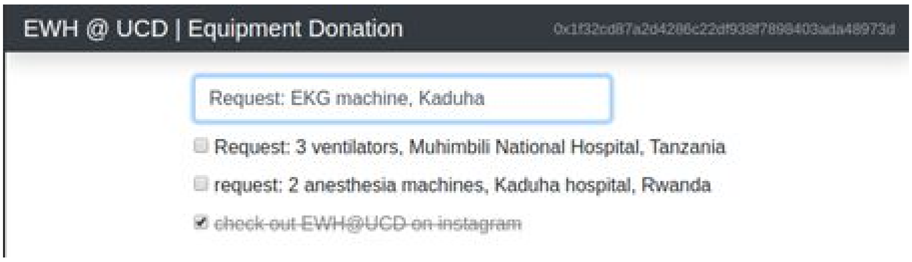
serial	mach_type	makemodel	manual	servinfo	prevmaint	nextmaint	disposal	contact
Filter	Filter	Filter	Filter	Filter	Filter	Filter	Filter	Filter

Appendix C - Blockchain Functionality

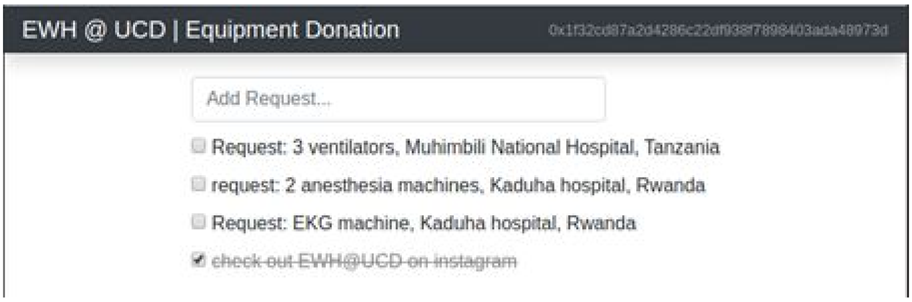
1. **App front end.**



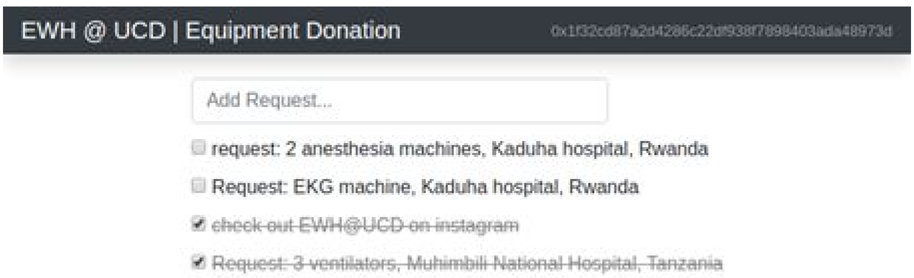
2. **Requesting a donation using the add request option**



3. **Updated list of donation requests**



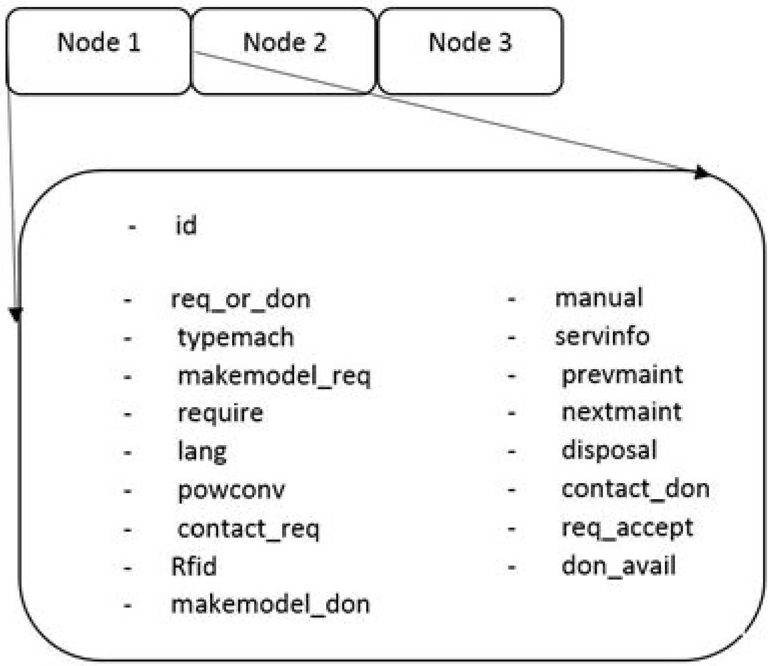
4. **Request fulfilment confirmation by a donor.**



5. Elements to be included in future implementation of blockchain app

- ID of the node (id)
- Donation request or adding donation (req_or_don)
- Type of Machine Required (typemach)
- The make and model desired (makemodel_req)
- Specific Requirements (require)
- The Language(s) understood in the hospital (lang)
- The Power Convention (powconv)
- Contact Details of the Hospital Requesting a Donation (contact_req)
- Serial Number on the RFID linked to the machine
- The make and model of the machine (makemodel_don)
- The user manual for the machine (manual)
- Any relevant service information (servinfo)
- When the previous maintenance occurred (prevmaint)
- When the next maintenance is scheduled (nextmaint)
- Any relevant disposal information (disposal)
- Contact information for the donor (contact_don)
- Donation request accepted or not (req_accept)
- Donation available now (don_avail)

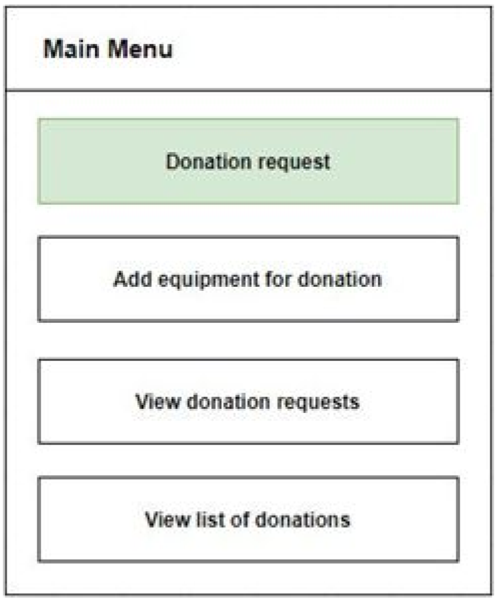
6. Layout of the blockchain node structure



7. **Donation details that user is prompted to input when requesting donation:**

    - Type of Machine Required (typemach)
    - The make and model desired (makemodel_req)
    - Specific Requirements (require)
    - The Language(s) understood in the hospital (lang)
    - The Power Convention (powconv)
    - Contact Details of the Hospital Requesting a Donation (contact_req)

8. **Schematic of app menu and option to request equipment donation (equivalent to Appendix C2)**

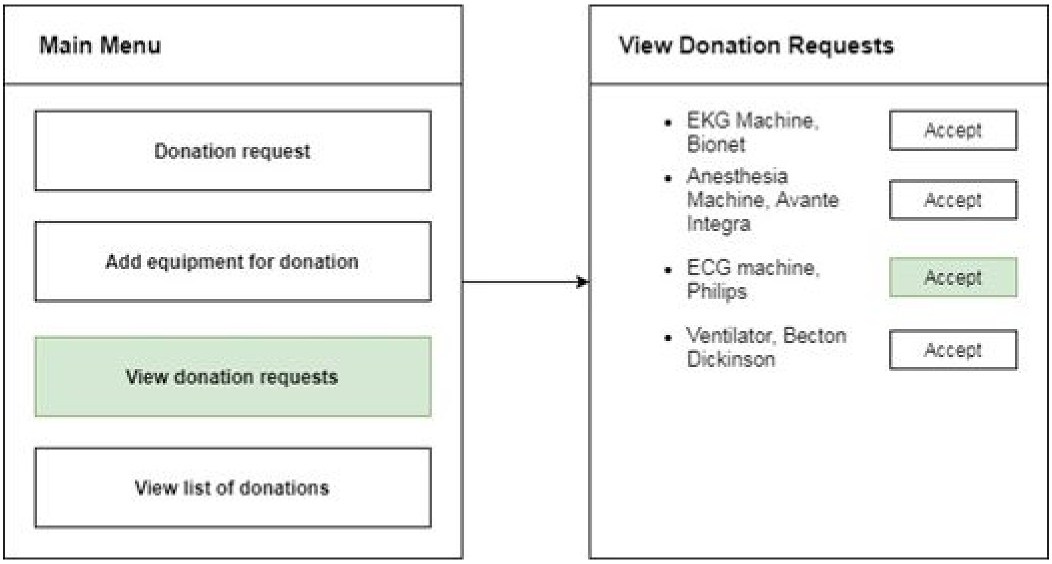


9. **Donation details that user is prompted to input when fulfilling a donation request:**

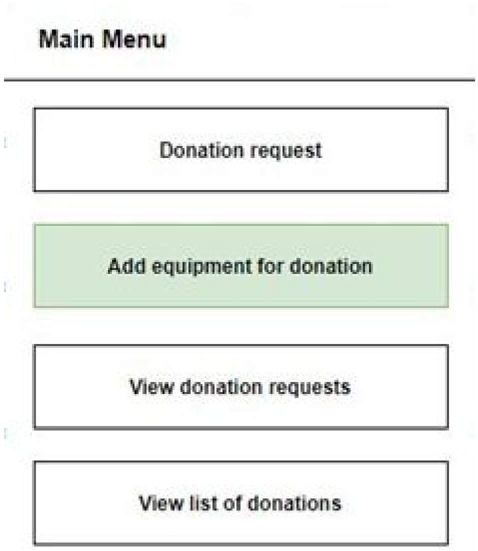
10. **Donation details that user is prompted to input when advertising a donation:**

    - Serial Number on the RFID linked to the machine
    - The make and model of the machine (makemodel_don)
    - The user manual for the machine (manual)
    - Any relevant service information (servinfo)
    - When the previous maintenance occurred (prevmaint)
    - When the next maintenance is scheduled (nextmaint)
    - Any relevant disposal information (disposal)
    - Contact information for the donor (contact_don)

11. **Schematic of app menu and viewing donation requests and accepting to fulfill a donation request (equivalent to Appendix C4).**

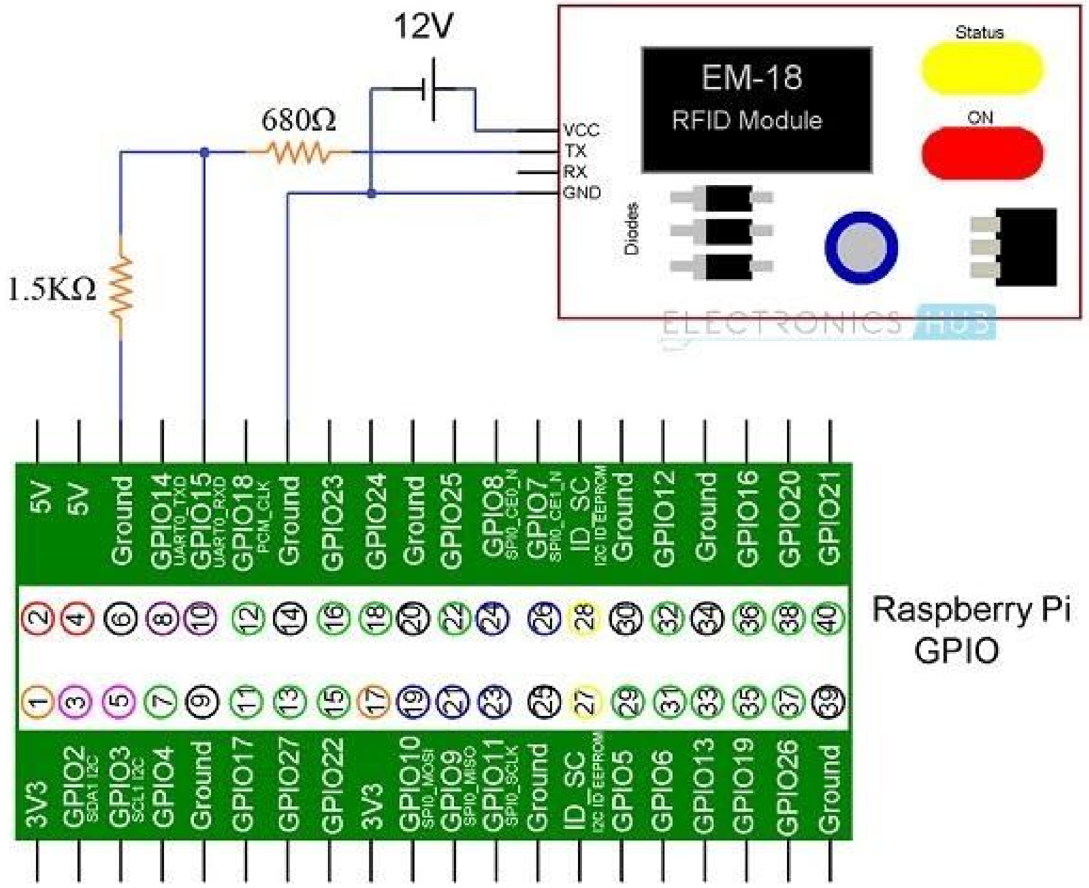


12. **Schematic of app menu and option to add equipment for donation by donors**



Appendix D: Circuit schematics

1. Raspberry Pi



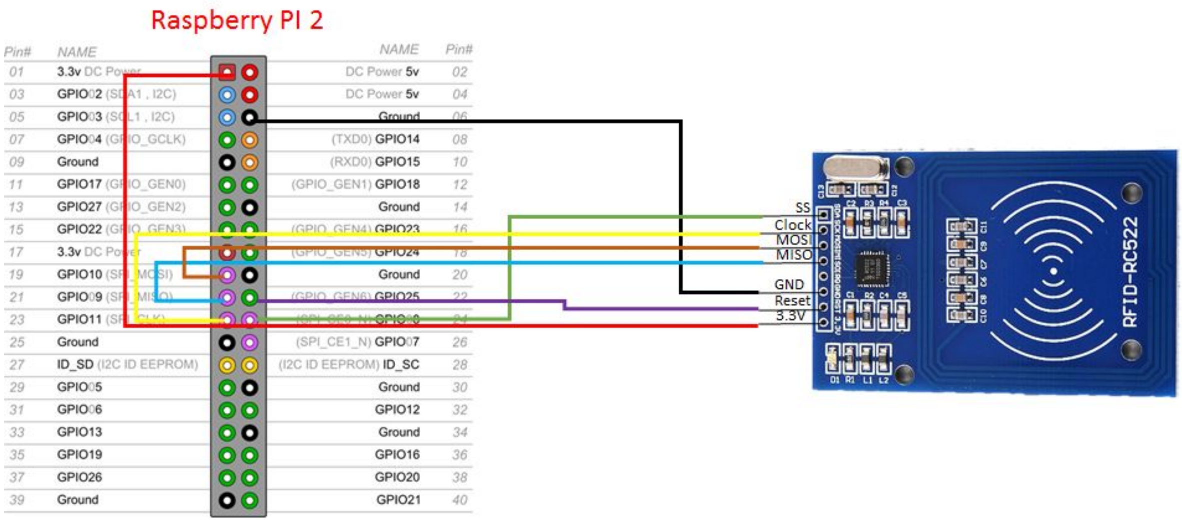


Image: RFID RC522 with Raspberry Pi 2 Model B

Source: https://site.ibeyonde.com/faq/configure-rfid-rc522-on-raspberry-pi/

2. Arduino

Arduino Uno

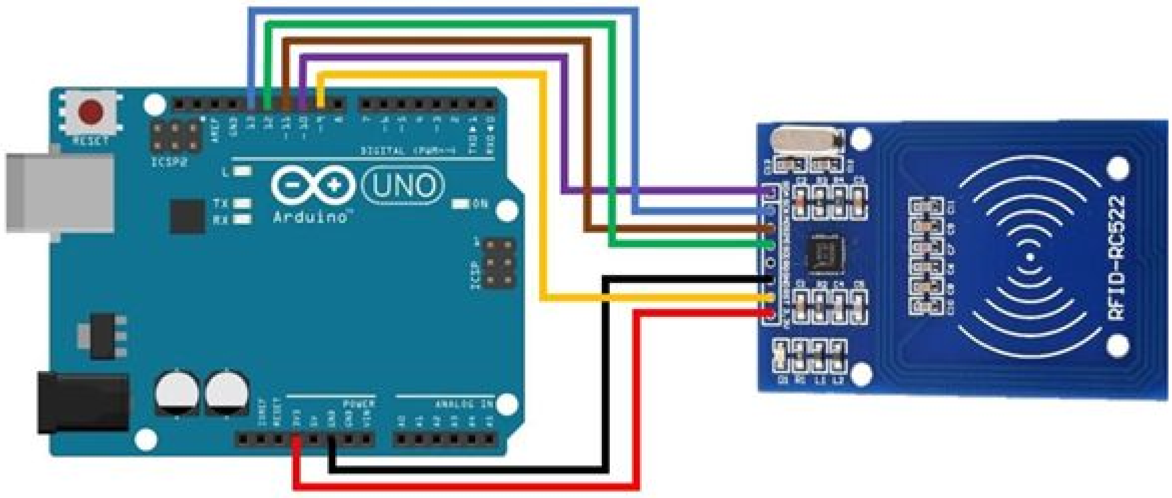


Image: RFID RC522 with Arduino Uno circuit

Source:https://circuits4you.com/2018/10/03/interfacing-of-rfid-rc522-with-arduino-uno/

Arduino Mega 2560

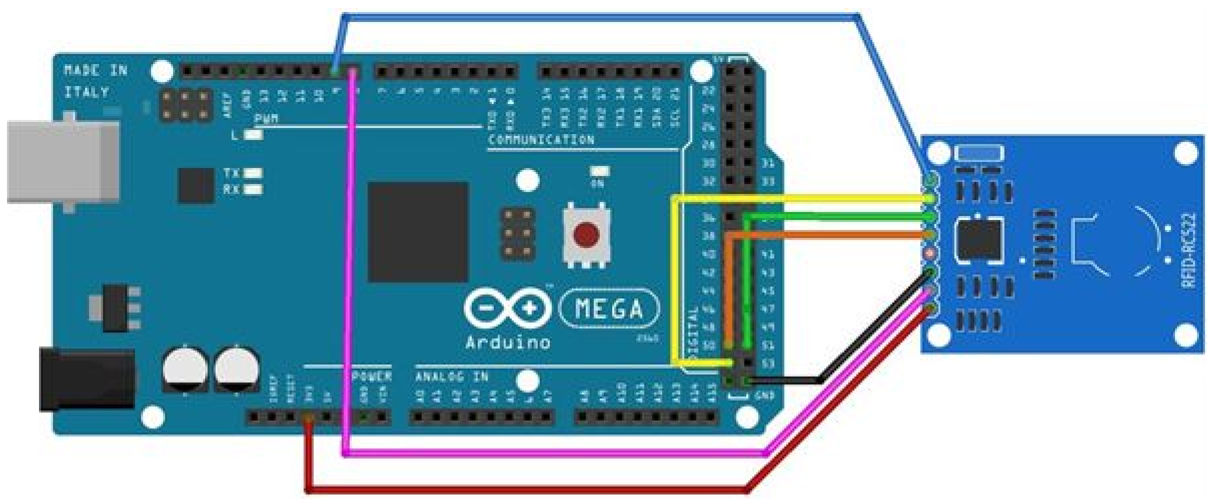
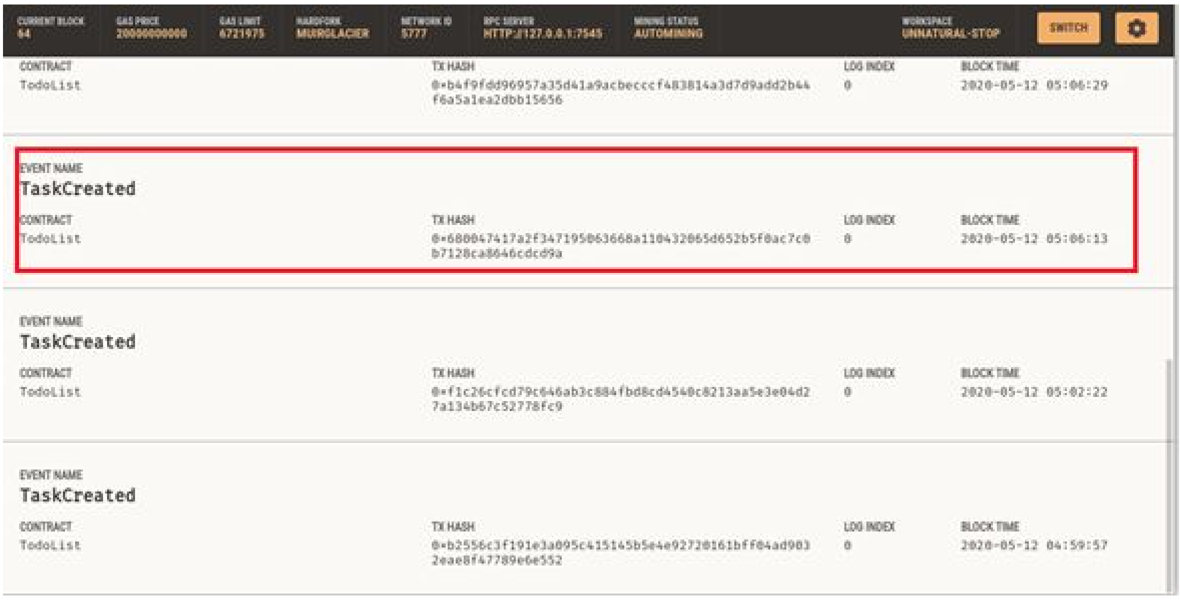


Image: RFID RC522 with Arduino Mega circuit

Source: https://www.instructables.com/id/Interfacing-RFID-RC522-With-Arduino-MEGA-a-Simple-/

Appendix E: Proof of Immutability

1. List of transactions indicating blocks in the blockchain



2. Details of the selected block