

Photogrammetry using a phone camera array

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Introduction

This project is intended for submission to the journal of HardwareX (<https://www.sciencedirect.com/journal/hardwarex>), which has a strong emphasis on the materials and methods. The following thesis is formatted according to the Faculty requirements, but also follows the journal's recommendations.

Hardware in context

Photogrammetry is a technique, photographs of the target from multiple angles are used for reconstruction of its 3D model. Recent advancements of algorithms and computing power made this method widely accessible. One of the main advantages that it allows building high precision 3D models without the need of special 3D scanners. When photogrammetric reconstruction of human bones were compared to their CT scans, it was found that photogrammetry is a reliable and accurate alternative [1].

Medical applications of photogrammetry is not a new concept [2], but it is only recently when this method became widely accessible and more widely adopted. Applications range from postural reconstruction [3], documentation of autopsies [4], teaching forensic medicine [5] to transtibial socket digitization [6], just to name a few.

One of the main limitations of photogrammetry in living subjects is that it needs a static target, as movement would change make the reconstruction impossible.

One potential solution for this problem is to connect several cameras pointing at the target and release them at the same time. Interestingly, one of the main users of this kind of rigs are the movie and video game industry to scan actors or "assets". The research field is also recognized this technique:

Leipner and colleagues created "3D mug shots" for forensic purposes with a system created by 26 Canon EOS 80D DSLRs, connected by USB and controlled by a workstation running Smart Shooter 3 [7]. Their upgraded system consisted 64 Canon EOS 1200Ds cameras [8].

Pesce et al. proposed a simple system using eight Canon Power Shot 480 cameras [9], but their system needed a calibration process.

VirtoScan is an ingenious solution of surface documentation of human cadavers by attaching 7 Canon EOS 100D DSLR cameras to CT scanner, and take photos during the full body CT scanning [10].

Richard Garsthagen published an open source system built from 98 Raspberry Pi cameras in 2014 [11]. The following project successfully networked 40 Raspberry Pi cameras for this purpose [12]. Yang et al described an open-source solution consisting of 50 Raspberry Pi cameras connected with routers [13]. They were able to capture high quality hand models, despite its surprising difficulty using photogrammetry.

Raspberry based solutions are relatively affordable compared to full fledged DSLR cameras, but building an array with dozens of cameras can be costly: a Raspberry Pi 4 2 GB board costs 45 USD, the additional Raspberry Pi Camera board v2 costs 30 USD. An other timely problem is that currently due to the chip shortage it is almost impossible to source Raspberry boards.

Hardware description

- Forming an array of mobile phones to capture images from several angles of the subject at the same time.
- It allows 3D reconstruction of living, moving subjects by photogrammetry.
- Inteded applications: face reconstruction, wound assessment.

The core of the system is a simple controller module, which connects to the phone with a 3.5 mm jack plug and emulates the press of volume + of a headset, to release the camera shutter. The design is based on the Android AOSP accessory specification (Fig. 1) (<https://source.android.com/docs/core/interaction/accessories/headset/plug-headset-spec>).

The R3 resistor (5000 Ohm) simulates the resistance of the microphone unit, the phone recognizes that a headset is plugged in by this resistance. R1 and R2 (330 Ohm and 22 Ohm) emulate the button press, when they are connected by the PC817 optocoupler. When the

optocoupler is turned on, an internal LED activates an internal phototransistor and closes that circuit. The advantage of using optocouplers over relays is that they are smaller, more reliable and use less energy. D1 diode is a protection against reverse polarity. R4 resistor drops the voltage of the battery for the optocoupler. The units are connected via JST XH 2 connectors. The design of the controller PCB (printed circuit board) is intentionally simple, using only through-hole components not the smaller SMD ones. With minimal soldering experience one can assemble them safely. Also, if someone can not order the PCBs from a manufacturing company, it is possible to etch it at home or build it on a prototyping board.

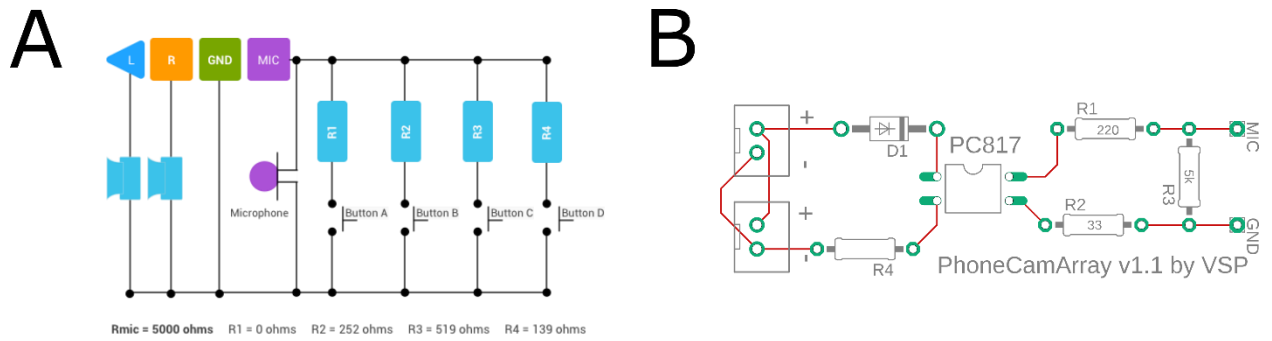


Fig. 1. The controller circuit. A. The schematics of the headset circuitry defined by the Android AOSP accessory specification [14]. B. The circuit of the control PCB.

The ideal frame of the camera array largely depends on the intended application. The structure will differ if one wants to fill a whole room with dozens of cameras or wants to create a portable version containing only four – six phones. It is possible to attach the phones to an existing object (for example a CT instrument). In this manuscript to simple, but modular frame is described. The first one consists of 1 * 4 cm wood columns with 3D printed, 135° joints. It offers easy scalability as the size of the frame depends only on the size of wood strips. The pieces fastened with woodscrews.

The second frame option is fully 3D printed and curved. It has the advantage, that every camera points to the same spot, but bigger buildplate is necessary. The pieces are joined by heated inserts and metric screws.

Materials and methods

Design files summary

Design file name	File type	Open source license
Junction box	STL and STEP	Creative Commons Attribution-ShareAlike 4.0 International License
Frame connector 1	STL and STEP	Creative Commons Attribution-ShareAlike 4.0 International License
Frame connector 2	STL and STEP	Creative Commons Attribution-ShareAlike 4.0 International License
Grip	STL and STEP	Creative Commons Attribution-ShareAlike 4.0 International License
Control grip	STL and STEP	Creative Commons Attribution-ShareAlike 4.0 International License
PCB	Gerber and Eagle	Creative Commons Attribution-ShareAlike 4.0 International License
Printed frame	STL and STEP	Creative Commons Attribution-ShareAlike 4.0 International License

Unless someone is very skilled, the use of ready made male-male JST XXX cables and male-male jack cables increases the reliability of the system compared to crimping and soldering the individual components.

Key components not listed above are the phones themselves.

The minimum requirements are:

- Take acceptable images with autofocus.
- Have a functioning: audio jack, Wifi adapter, screen and battery.
- A cracked screen, cosmetic defects or old Android version does not affect the use of in this project.

Software used to design and create this project:

- Fusion 360 (Autodesk) for design the case and grips. Free for hobbyist use or with an educational license.
- EAGLE (Autodesk) to design the PCB. Free for hobbyist use or with an educational license.
- Cura slicer (Ultimaker) to slice the 3D models for printing.

Tools and materials used for assembly:

- An FDM 3D printer with a build plate minimum of 220*220 mm.
- Soldering iron and solder.
- Multimeter.
- Saw to cut wood frame.
- Side cutter pliers.
- Wire stripper.
- Glue (cyanoacrylate or E5000)

Preparing the phones

Ideally one can assign decommissioned Android phones permanently to this task. It is recommended to create a separate account for this purpose.

The following steps are advised to perform on all the phones used. It is rather a guideline than a detailed description because the exact settings can differ between manufacturers, software versions and languages.

- Perform a factory reset.
- Restart the phone and sign in with the newly created credentials.

- Connect to the Wi-Fi network.
- Disable lock screen lock.
- Disable the unnecessary applications (almost everything).
- Turn off Bluetooth, location to conserve battery.
- Update the operating system and all the remaining applications.
- Go to settings and set screen timeout the longest possible interval.
- Download Autostart APP from the Play store.
- Set up Autostart APP to start Camera app after boot..
- In the Play store disable auto update of applications.
- Start the camera application and check if the press of the volume button releases the trigger. If it has not taken an image, enable the option to “take photo by pressing volume button” option.
- Additional settings of the camera app: enable HDR mode and autofocus. Turn off LED flash.

One of the best features of using mobile phones is their ability to automatically backup the photographs to a central repository. On Android phones the simplest method is using Google Photos backup option. On Huawei phones, running Harmony OS, Huawei Mobile cloud offers the same feature. The OneDrive app (Microsoft) also allows the backup function. If someone is running their Network Attached Storage (NAS), then the manufacturer of the NAS often provides applications, such as DS photo (Synology), Qphoto (QNAP) or ZyXEL photo (Zyxel). It is also possible to set up an FTP server for this purpose. In the case of concern of cloud services, one can set up a local WiFi network without internet access to connect the phones and a local server/NAS.

Preparing the jack cables

- Cut the male – male 3.5 mm aux cables to half (Fig. 2).



Fig. 2. Cutting the male – male aux cable to half.

- Strip the outer insulation layer (Fig. 3).



Fig. 3. The external insulating layer removed.

- Twist the outer shielding metal wires. (Other cables might lack this shielding layer of metal wires. In that case it should contain four individually insulated inner cables.)

- Check which wire corresponds to the microphone (innermost pad on the male jack plug) and the ground (next to the innermost pad of the plug) (Fig. 4). It can be performed with the continuity testing function of a multimeter.

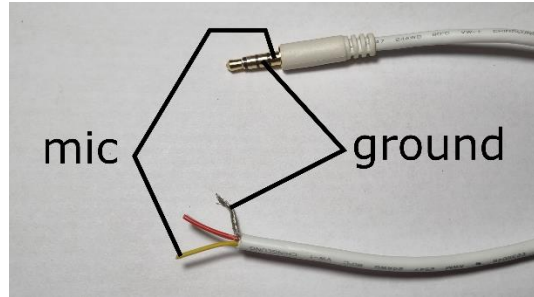


Fig. 4. Shielding outer metal mesh is twisted. The lines corresponding to MIC and GND are identified.

- Cut off the wires corresponding to the left and right sides. Strip the end of the mic line.

Making the circuit boards

The gerber files attached to the manuscript contain all the necessary information for PCB manufacturers (e.g JLCPCB (jlcpcb.com), PCBWay (pcbway.com), just to name a few) to create boards. To order the boards, after registration only the gerber files should be uploaded. Leave additional setting on default.

Because of the simple layout, it is possible to etch the boards at home, using the 'control PCB – DIY.svg' file (Fig 5). The paths are enlarged to facilitate DIY etching.

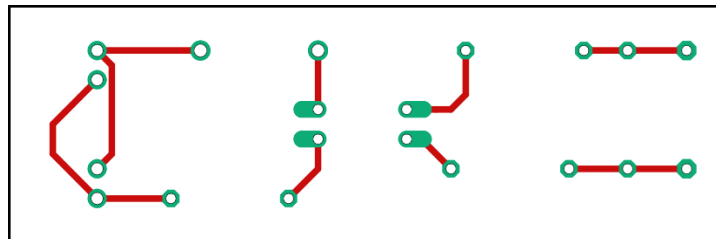


Fig. 5. Control board PCB modified for DIY etching.

It is even possible to create the circuit board using prototype PCB boards. Building several boards this way is time consuming and the holder box ought to be resized, this these versions should be functional as well (Fig 6).

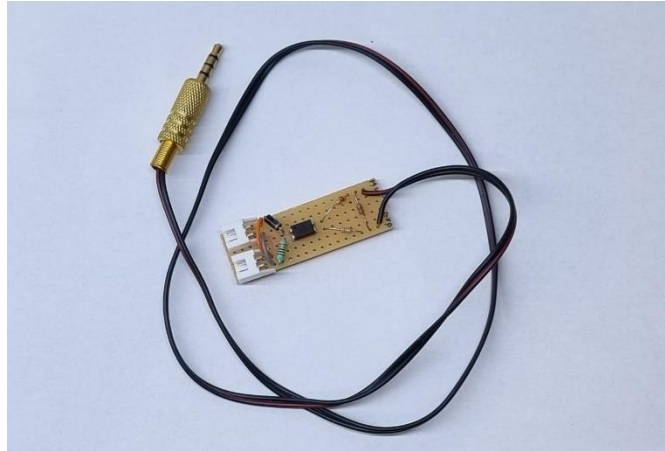


Fig. 6. A control circuit built of prototyping PCB.

Assembly of the control circuit

Soldering the components should pose no major challenge with minimal experience.

- The resistors have no polarity, they can be soldered in both direction.
- The grey line found on the diode should line up with the marking on the PCB (Fig 7.)

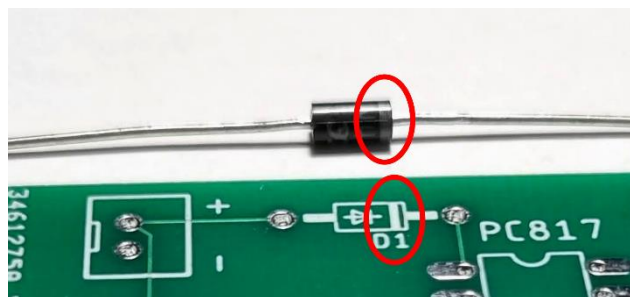


Fig. 7. Orientation of the diode.

- One corner of the optocoupler is labeled with a small circular indent. It must point towards the connectors (Fig. 8).

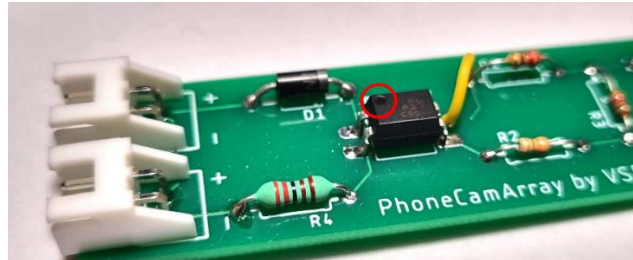


Fig. 8. The circular indent on the corner of the optocoupler must point towards the connectors.

- Solder in the jack cable. Even if the MIC and GND is labelled on the PCB, orientation is not crucial.
- When the assembly is completed, it is recommended to test each boards individually.
- The finished board can be inserted to the protective box. The JST connectors should be pushed through their designated cut out, then the other end of the board should be pushed down (Fig 9). It should click in place.

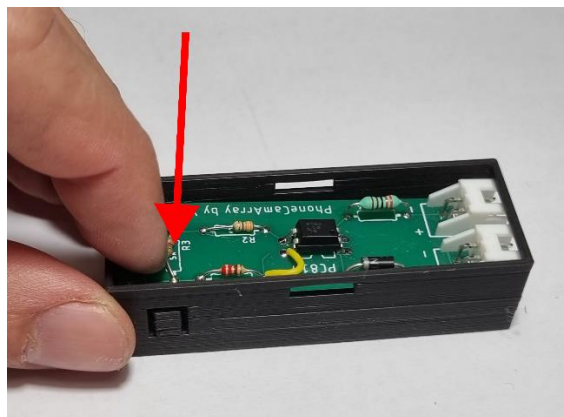


Fig. 9. Inserting the PCB into the protective box. The clips should hold it in place.

Print settings

All the 3D printed parts were designed with FDM printing in mind. None of the 3D printed components of this project should be a challenging print, without the need of supports or rafts. Polylactic acid (PLA), which is the most common material in FDM printing, is suitable, but PETG, ASA or ABS can be considered as well.

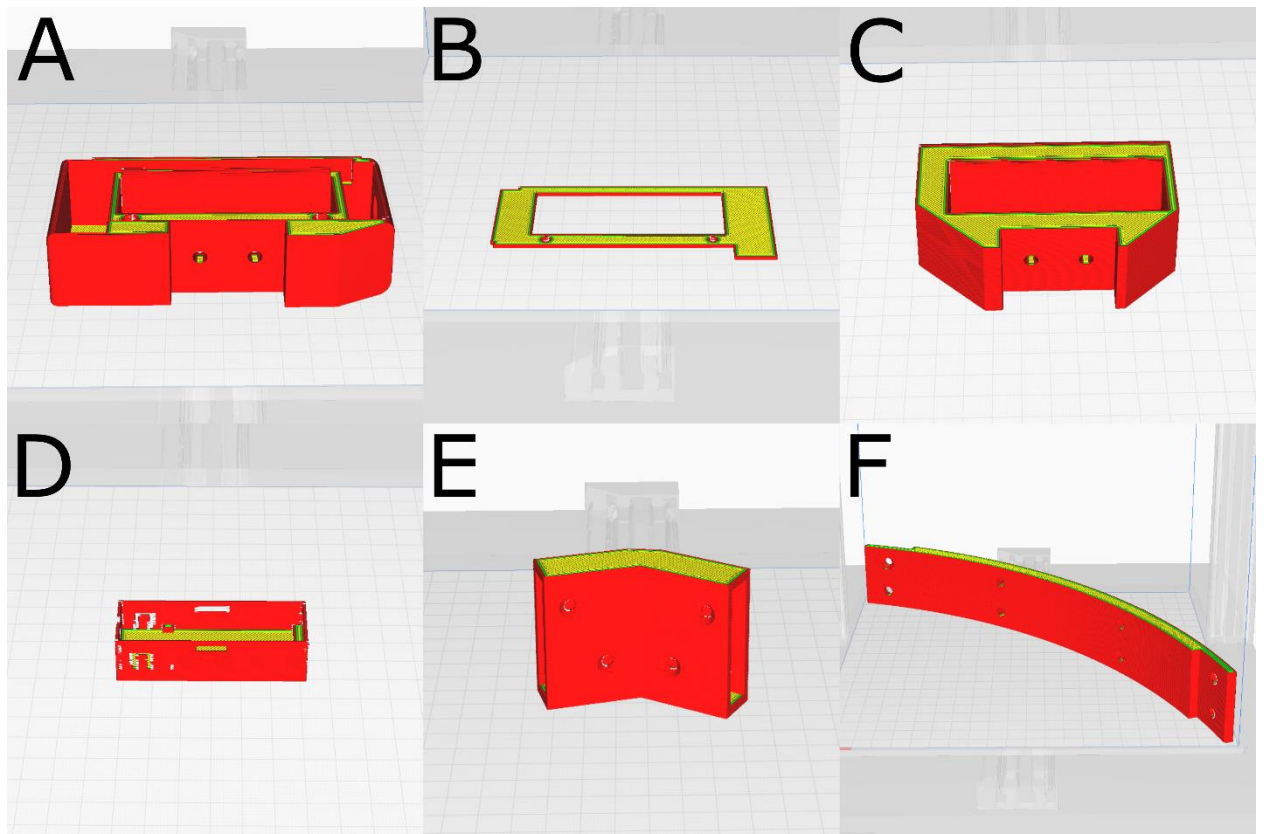
The exact printing parameters can differ between filaments and printers, the following tools and settings were used:

Printer: Artillery Genius, nozzle diameter: 0.6 mm.

Filament: Filanora PLA BIO HI. Hot end temperature: 220 °C. Build plate temperature: 60 °C

Slicer: Cura Line width: 0.8 mm. Wall count: 3. Infill 10 %. Bridging mode enabled.

Recommended printing orientations can be seen on Figure 10.



Assembly of the frame

Heat inserts are a versatile and affordable tools to create strong separable connections. In this design brass inserts are used to connect the 3D printed frame modules and holds the cover of the control grip. A short description of installation of heat insert can be seen on Figure 11. It might be necessary to remove bulging plastic after the installation with an x-acto knife.

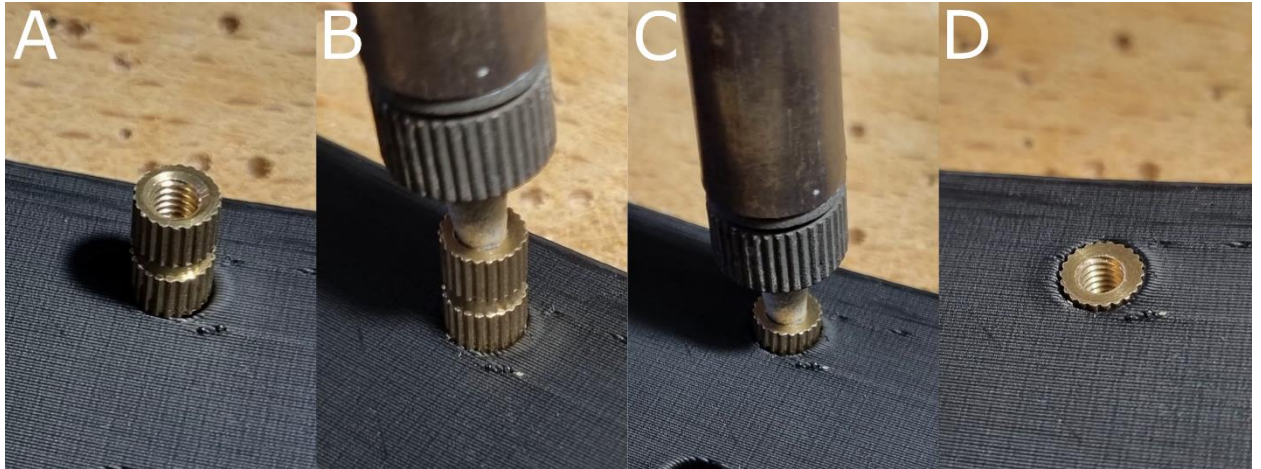


Fig. 11. Installation of the heat inserts. A. Place the right sized insert over the hole. B. Heat up the insert with the tip of a soldering iron. C. Gently push the insert downwards by the soldering iron. Keep is perpendicular to the surface. D. The seated insert.

Control grip

- Press fit the M4 nuts and insert the M3 heat inserts. (Fig 12.)

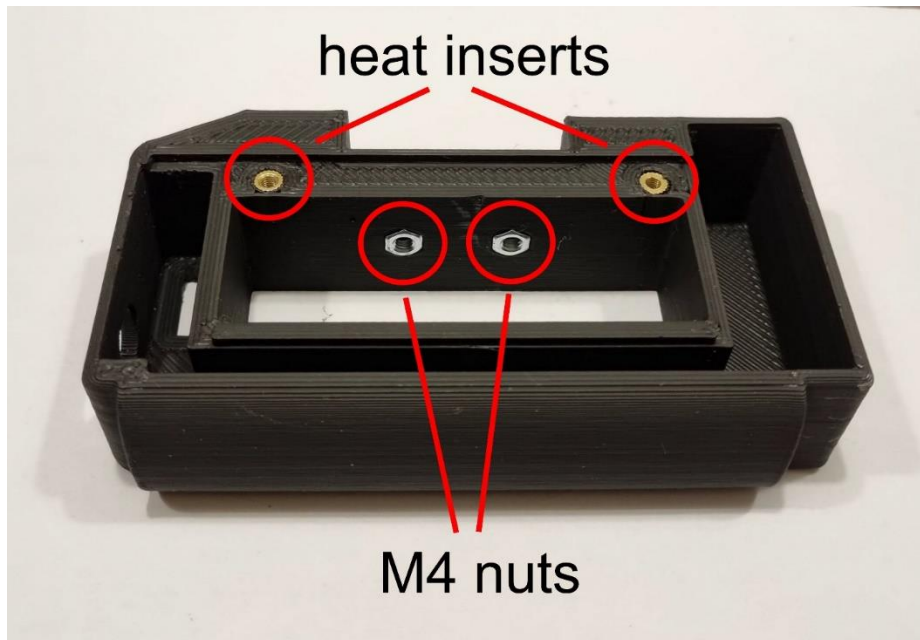


Fig. 12. The position of heat inserts and M4 nuts of the control grip.

- Connect the shutter release button with the 9 V battery terminal and the JST connector panel by soldering. (Fig 13.)

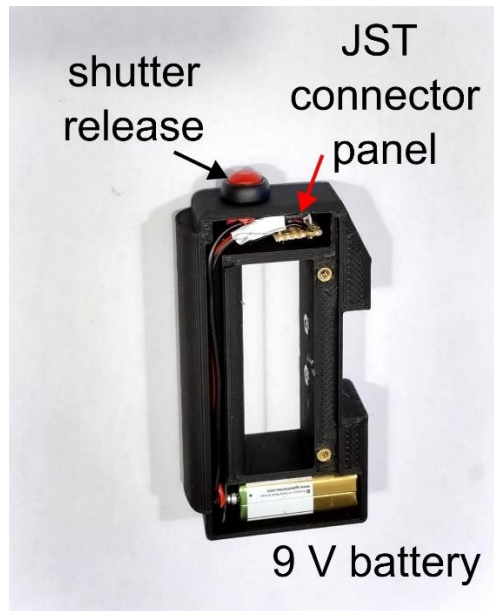


Fig. 13. The internals of the control grip.

- Screw on the cover of the control grip with M3 screws. (Fig 14.)



Fig. 14. The control grip with the cover.

Connecting the components

Connect all the phones to their control boxes via the 3.5 mm audio jack cables. Daisy chain the control grip and the control boxes with the JST-XXX cables (Fig. 15).

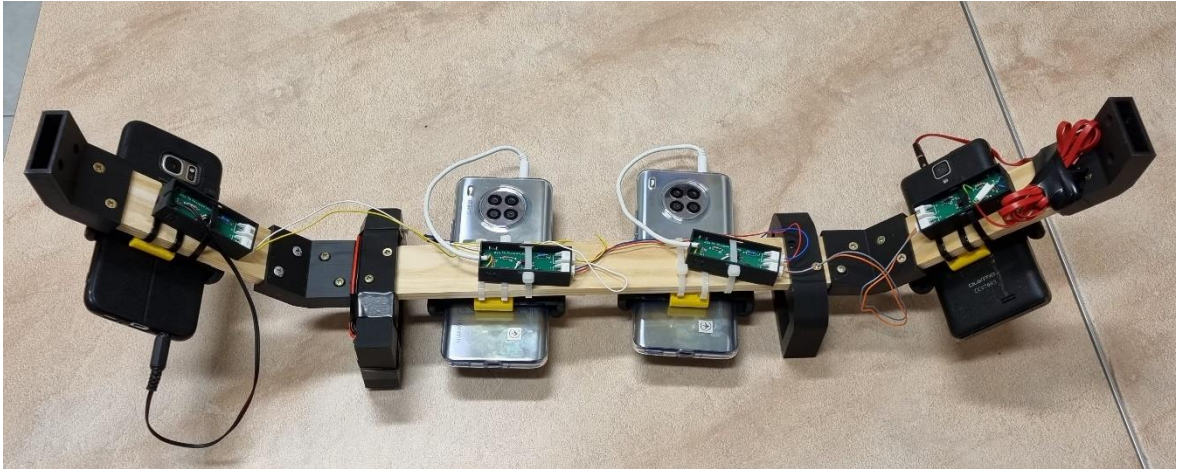


Fig. 15. The assembled phone cam array.

Operational instructions

- Turn on all the phones.
- Wait until all the devices start up.
- Press the shutter button once.
- Verify if all the phones have taken an image.
- Ask the subject not to move during taking the images, if necessary.
- If a handheld frame is used, hold it steady while capturing the images.

The phones can be charged individually until only a few used. A powered USB hub attached to the frame with USB cables permanently plugged into the phones can keep them charged.

Even lighting and sharp, in-focus images are the two most important keys of successful photogrammetry. A detailed description of this topic is explained in Supplementary material of the following publication by Tóth et al [5].

Photogrammetric reconstruction of 3D models can be performed with specific software applications. In this project, all the processing was performed with Autodesk ReCap Photo. A detailed step-by-step description of the process can be found in the second Supplementary file of the paper by Tóth et al [5].

Results and discussion

Characterization of the phones

The phones used in this proof-of-concept project are listed in Table 1. The Huawei phones are current mid-range models, the Samsung is an old flagship, while the Oukitel is an old entry-level one.

Manufacturer	Model	Released	Camera		
			Resolution (megapixel)	Aperture	Focal length (35 mm equivalent)
Huawei	nova 8i	2021 July	64 (16*)	f/1.9	~27 mm
Samsung	S7 Edge	2016 March	12 MP	f/1.7	~26 mm
Oukitel	K4000 Pro	2015 August	8 MP	f/2	n.a.**

Table 1 Phones used in this pilot project. * The resolution of the sensor is 64 megapixels, but in normal camera mode, it is subsampled to 16-megapixel images. ** The equivalent focal length is roughly the same as of the other two phones.

Measuring the shutter lag

To measure the time delay of the different cameras, the stopwatch was started on an iPad then pictures were taken at its screen with the camera array (Figure 16). The time delay was calculated from the pictures taken with the same exposure.



Fig. 16. Testing the release lag between the cameras.

A constant trend was that the Samsung took the images first, it was followed by the Huawei and the Oukitel was the slowest. At the initial measurements its average delay compared to the Samsung was almost 1 second (966 ms). With the simple tweak of turning on the continuous autofocus mode of the Oukitel decreased the delay significantly to 636 ms (Table 2). The average difference between the two Huawei phones were 160 milliseconds (SD: 107 ms). Yang and colleagues reached 80 ms lag between identical Raspberry Pi cameras [13].

	Oukitel K4000 Pro	Huawei nova 8i (A)	Huawei nova 8i (B)
Delay (ms)	636	362	522
SD (ms)	45	46	109

Table 2. Delay of exposure compared to the fastest camera (Samsung S7 edge). Mean of five measurements. All units are milliseconds.

Wound scanning

In this study the main aim was to create a multicamera system for wound and injury documentation. To test this the handheld camera array was used to take several images of two cadavers as a proof of concept.

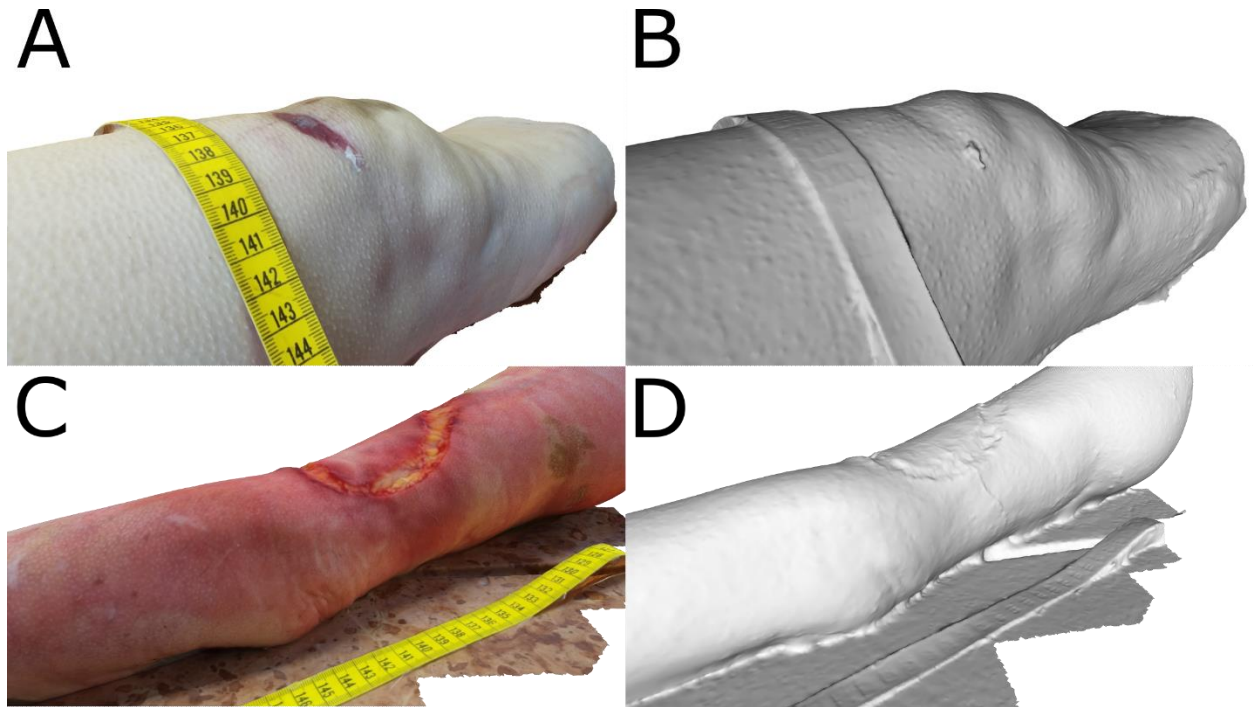


Fig. 17. Three dimensional reconstruction of wounds of limbs. A. A Abrasion above the knee cap with texture. B. The same model without textures. The resolution of the 3D model is shown by the visible goosebumps and the epidermal tag. C. Continuity disruption affecting the full thickness of the skin with slightly irregular edges caused by extreme heat trauma. D. The same model without textures.

As it can be seen on Figure 17, this system was able to capture images for high quality 3D model reconstruction what paves the way for a full camera array.

Limitations

- Photogrammetry is scaleless. An object of known size (for example a ruler or tag) must be included on the pictures, what will serve as a calibrator after the model reconstruction.
- Probably a similar system could be built of iPhones, but the control box of this system is using Android or Harmony OS specific signals.
- The average latency between the different phones was 636 ms. It could be improved by using the same type of phones (in the case of two Huawei nova 8i models, it was 160 ms), but it might be still not enough to capture very fast movements.
- If a full cage array is built, the devices might block too much light. It could be countered by attaching LED strips to the vertical rods of the frame.

Acknowledgments

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Ethical approval

The photogrammetric reconstruction of human bodies was approved by the Regional Research Ethic Committee, Pécs (8836 – PTE 2021).

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