

# Cordless portable multi-view fringe projection system for 3D reconstruction

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## Abstract

*A newly devised lightweight sensor head, combining a digital LED projector and two cameras in a stereo arrangement with access to even complicated measurable object details, is presented. It uses a pre-calibrated, epipolar constrained, phase correlation based fringe projection approach. The mobile unit is battery powered and data transfer is done via WLAN to enable flexible use in complex measurement situations. Multi-view measurement is realized using the phasogrammetric approach with virtual landmarks. Thereby the system enables whole-body measurement without matching procedures or markers. The mobile character suggest application in arts, design, archaeology and criminology.*

## 1. Introduction

Recent advances in miniaturization have allowed for the realization of an ultra mobile 3D sensor, which combines the advantages of structured light scanners with handheld systems. Key preconditions for the usage of fringe projection in such a system are a bright, mobile digital projector and high frame rate cameras. The combination of cable free design and highspeed image projection with a low triangulation angle stereo camera setup allows access even to complicated object details and a highly flexible, intuitive user interaction. This poster presents our approach for such an ultra mobile optical 3D sensor. We focussed on true wireless design, including wireless camera-projector synchronization and data transfer over WLAN. This allows for hassle-free and convenient walk-around scanning.

## 2. System details

The measurement system uses phase correlation based fringe projection. This technique casts two sequences of fringes rotated by  $90^\circ$ , generated by a digital projector, onto an objects surface. The projected pattern is observed by two cameras at the same time. Sub-pixel accurate pixel correspondences for every pixel from this image sequence are calculated. These correspondences in turn enable the

precise 3D coordinate calculation using triangulation. The schematic of the mobile sensor head and the whole system are shown in Fig. 2 (a) and (b), respectively.

### 2.1. Usage scenarios

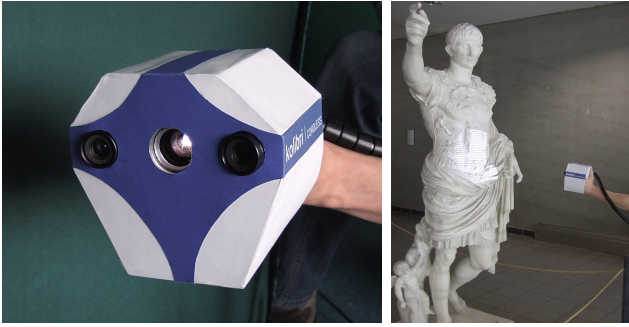
Short setup time, a lightweight and highly mobile sensor and high speed image projection enable a new degree of freedom in 3D scanning. Two typical usage scenarios are given below:

**Multi-view measurement with self-calibration:** In this mode the sensor system operates in the phasogrammetric approach in combination with the concept of virtual landmarks introduced by the authors. Multiple views of (portions of) the object are taken by the sensor. One or more cameras attached to the base unit monitor the whole scene and enable the self calibration process. Hereby an additional camera (static to the object) makes interrelating multiple views of the object possible without additional markers, sensor tracking or registration / matching procedures. After all views are acquired a point cloud / triangulated surface containing the entirety of views is calculated.

**Multi-view measurement with registration:** If an additional camera is not desired or available, the sufficiently overlapping single views can be registered by post processing / matching procedures. Such operations are usually provided with off-the-shelf point cloud processing software. This approach offers short system setup time, great freedom in viewpoint selection and requires no linking camera.

### 2.2. Algorithmic challenges

**High frame rate capture:** The calculation of phase values from multiple images requires, that the same pixel of each source image of the whole set observes the same object region – the sensor is virtually static. Experiments showed, that this can be achieved for the given sensor setup, if the sequence is shorter than 150 ms. Therefore we implemented a crossed sinusoidal fringe sequence of  $2 \times 4 = 8$  images at 60 fps, yielding a total sequence duration of 133 ms. To ensure proper timing between image projection and capture, we adopted a RF based, electronic synchronization.



(a) Photo of sensor head (b) Large sculpture

Figure 1. Sensor head photo (a) and application example (b).

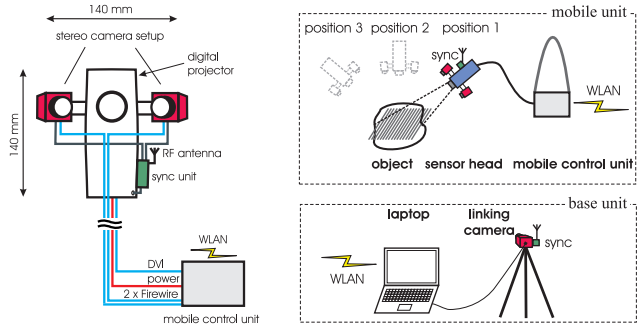
**Low image count:** To reduce the used fringe sequence down to 8 images, we had to omit the normally included gray code images. In order to still obtain semi-absolute phase values needed for 3D coordinate calculation, we had to make use of the epipolar constraint of the given stereo camera setup. After phase calculation and rectification, an initial solution to the phase unwrapping problem in multiple appropriate regions is calculated. Subsequently this solution is propagated to adjacent lines.

**WLAN data transfer:** As precondition for the desired flexible use of the sensor for walk-around scanning, the mobile unit wirelessly communicates with the base unit. While several cameras transmitting images wirelessly are available, this method would have seriously decreased the achievable image rate. Therefore we chose miniaturized IEEE 1394 cameras attached to an embedded system, which also handles sequence projection, camera buffering & control and on-the-fly data transmission via WLAN.

### 2.3. System setup

To enable handheld, yet comfortable scanning, the weight of the sensor head had to be limited. This led to the split-up of the mobile unit into the handheld sensor head (see Fig. 1 (a) and 2 (a)) and the wearable mobile control unit (see Fig. 2 (b)). This way we could restrict the sensor head's weight to about 950 g. The sensor head measures about  $130 \times 160 \times 140$  mm (L x W x H) and consists of two cameras and a miniaturized projector. One realized configuration yields a measurement field of about  $220 \times 170$  mm at a working distance of 400 mm, delivering an average point distance of 0.35 mm. Other configurations in the working distance range from 250 mm to 1000 mm are possible.

The IEEE 1394 cameras deliver a resolution of  $658 \times 494$  pixel at 60 Hz. They are grouped in a stereo arrangement with a triangulation angle smaller than  $20^\circ$  in order to gain access to complex object areas. Despite the projector's miniaturization, it offers a bright image at a resolution of  $800 \times 600$  pixel thanks to the utilized LED illumination



(a) Sensor head schematic (b) Mobile and base unit

Figure 2. Schematics of system components.

technology.

Auxiliary components will be carried in a shoulder bag. They include an embedded system and battery. Advantages of the mini ITX based embedded platform are the available high processing power and the integrated power supply of the cameras over the FireWire cable. Estimated typical operating time per battery charge is 2h.

The mandatory synchronization between sensor head and linking cameras for 60 Hz operating regime is done via RF communication. The images from the sensor head are captured under control of the embedded system. After pre-processing, they are sent via WLAN to the PC at the base unit (e.g. a laptop), where 3D coordinate calculations take place and the user can monitor the scanning process.

### 3. Results

As an application example, the scanning of a large sculpture is shown in Fig 1 (b). Multiple single views are taken and combined to form the complete statue's surface using the virtual landmark approach.

In this poster we presented a novel handheld solution for optical 3D reconstruction. A mobile unit, consisting of a lightweight sensor head and a mobile control unit, transmits measurement results wirelessly to a base unit. Because the mobile unit is battery powered and synchronized via RF communication with the base unit, no cables restrict the operator's movements. This in turn offers an easy, intuitive and flexible way of use.

The utilized measurement principles of high speed digital fringe projection, phasogrammetry, phase correlation and virtual landmarks allow good resolution in object surface normal direction and robust multi-view registration. The resulting whole-body 3D reconstruction capabilities independent of object color, texture and erosion, can be applied to arts, design, archaeology and criminology. New application areas can be developed, where conventional 3D sensors didn't offer the required flexibility, portability, speed and resolution.