

A MINI UNMANNED AERIAL VEHICLE (UAV): SYSTEM OVERVIEW AND IMAGE ACQUISITION

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International Workshop on

"PROCESSING AND VISUALIZATION USING HIGH-RESOLUTION IMAGERY"

18-20 November 2004, Pitsanulok, Thailand

KEYWORDS: UAV, AUTONOMOUS, FLIGHT PLANNING, GPS/INS, CULTURAL HERITAGE

ABSTRACT:

In the last years UAV (Unmanned Aerial Vehicle)-systems became relevant for applications in precision farming and in infrastructure maintenance, like road maintenance and dam surveillance. This paper gives an overview about UAV (Unmanned Aerial Vehicle) systems and their application for photogrammetric recording and documentation of cultural heritage. First the historical development of UAV systems and the definition of UAV-helicopters will be given. The advantages of a photogrammetric system on-board a model helicopter will be briefly discussed and compared to standard aerial and terrestrial photogrammetry. UAVs are mostly low cost systems and flexible and therefore a suitable alternative solution compared to other mobile mapping systems.

A mini UAV-system was used for photogrammetric image data acquisition near Palpa in Peru. A settlement from the 13th century AD, which was presumably used as a mine, was flown with a model helicopter. Based on the image data, an accurate 3D-model will be generated in the future. With an orthophoto and a DEM derived from aerial images in a scale of 1:7 000, a flight planning was build up. The determined flying positions were implemented in the flight control system. Thus, the helicopter is able to fly to predefined pathpoints automatically. Tests in Switzerland and the flights in Pinchango Alto showed that using the built-in GPS/INS- and stabilization units of the flight control system, predefined positions could be reached exactly to acquire the images. The predicted strip crossings and flying height were kept accurately in the autonomous flying mode.

1. INTRODUCTION

1.1 Aims

In the past Unmanned Aerial Vehicles (UAVs) used in the photogrammetric community were not defined precisely. Therefore, the historical background for the development of UAVs and their different definitions in the literature will be explained. The ancient settlement of Pinchango Alto and the accomplished field work there will be described briefly.

UAVs are mostly used in military applications for recognition, environmental observation, maritime surveillance and mine removal activities. Non-military applications are environmental surveillance, rice paddy remote sensing and spraying as well as infrastructure maintenance.

The photogrammetric applications of UAVs will be discussed in more detail.

Here first the helicopter system and specification will be described. Furthermore, the camera system, which is mounted on the RC (Remote Controlled)-helicopter, is displayed.

Flight planning and preliminary results of the measurements in Pinchango Alto will be described and an easy flight planning

technique will be demonstrated. Finally, the occurred problems and results of the flights will be discussed.

Conclusions and future work show our future plans with the dataset Pinchango Alto. Furthermore some future plans and development of the helicopter system will be discussed.

1.2 Definition and Historical Development of UAVs in Photogrammetry

The name UAV covers all vehicles, which are flying in the air with no person onboard with capability controlling the aircraft. This term is used commonly in the computer science and artificial intelligence community, but terms like Remotely Piloted Vehicle (RPV), Remotely Operated Aircraft (ROA), Remote Controlled Helicopter (RC-Helicopter), Unmanned Vehicle Systems (UVS) and model helicopter are often used, too. The RC- and model helicopters are clearly defined by the Unmanned Vehicle Systems International Association as mini, close short and medium range UAVs depending on their size, endurance, range and flying altitude. UAVs like Pegasus (Everaerts, 2004) are better described as a long endurance UAV. Because of the focus on UAV helicopters in this paper, the different types of long endurance UAVs and aircrafts are

not treated in detail in this paper (more information in UVS, 2004).

The definition of the UVS community, in which the helicopters fit, are listed in Table 1-1. All other kinds of aircrafts are generalised in the “High Altitude Long Endurance” group.

Category name	Mass [kg]	Range [km]	Flight Altitude [m]	Endurance [hours]
Micro	< 5	< 10	250	1
Mini	<25/30/150	< 10	150/250/300	< 2
Close Range	25 –150	10 – 30	3000	2 – 4
Medium Range	50 –250	30 – 70	3000	3 – 6
High Alt. Long Endurance	> 250	> 70	> 3000	> 6

Table 1-1: Extract of UAV categories defined by UVS-international. In the Mini UAV category the numbers depend on the scope of different countries.

The development of UAVs has been strongly motivated by military applications. After World War II, some nations were looking for aerial vehicles, which have the capability for surveillance, reconnaissance and penetration of hostile terrain without the deployment of human beings in areas of high risk. The technical requirements can be defined by autonomous take-off, flying and landing (Eck, 2001).

Przybilla and Wester-Ebbinghaus 1979 did the first experiments with UAVs in photogrammetric applications. For image flights in a scale of 1:1000 or more, with a shutter speed of 1/1000 s, the velocity of the aeroplane was too high to get acceptable image motion. At that time, results were not sufficient because of the vibrations caused by the rotor which resulted in image motion. First tests accomplished using a model aeroplane by the company Hegi were flown (Figure 1-1). The aeroplane was 3 m long and had a wing span of 2.6 m. The plane could carry a payload of max 3 kg. Navigation equipment by Lindhof Technika was used to navigate the aeroplane. The system could determine the flying height from the size of the plane in the image viewer. The flights were done in a height of 150 m above the ground and with a velocity of 40 km/h. With this system, it was possible to acquire images of an archaeological area, architecture and building sites. Furthermore, the combination of terrestrial and aerial measurements was carried out. The application of this model aeroplane was limited by a small runway nearby the object, which was necessary. From this reason, the authors proposed to use less vibration-sensitive model helicopter.

In 1980, Wester-Ebbinghaus used firstly a model helicopter for photogrammetric purposes. The helicopter was a Schlueter model Bell 222 with a maximum payload of 3 kg. Polystyrene walls for effective clamping suppresses were installed on the helicopter to compensate the vibrations. Medium format cameras like a Rolleiflex SLX or Hasselblad MK 20 could be mounted on the helicopter system. For flight operation, a pilot and a navigator were needed. The pilot controlled the take off, landing and flying. The navigator had to control the altitude and to activate the camera shutter via radio link. The helicopter had a height range from 10 m to 100 m and the predicted height could be kept within 90 %, using the same navigation equipment like the aeroplane model. The Schwebbahn

(monorail) Wuppertal, a steel construction dating from 1890, was documented using the helicopter system (Wester-Ebbinghaus, 1980).

The development of UAVs and the integration of GPS/INS data onboard of UAVs are more and more discussed in the UVS international community (UVS-international, 2004). The background and development of mini UAV helicopter systems are shown in Eck (2001), WITAS (2004) and Conway (1995).



Figure 1-1: Model airplane Firma Hegi, Przybilla 1979.

The UAV-systems until then had mostly problems with holding the predicted altitude and in the navigation of the UAV. Through the small payload, these systems could only use few camera-systems, therefore mini UAV-systems did not establish at that time.

1.3 Project Pinchango Alto

The field measurements in Palpa (Peru) were done in cooperation with the German Institute of Archaeology, Commission for General and Comparative Archaeology (KAVA) in Bonn (Germany) as a part of the project network NTG which applies new technologies from the natural sciences inside the humanities.

Pinchango Alto is an old settlement area (200 m x 300 m), see Figure 1-2, from the 10th to the 14th century, which was presumably used as mine and processing facility by the ancient population. Rubbing stones and mica were found in the settlement area. Reindel (2002) proposed the function of Pinchango Alto as gold mining settlement, but this hypothesis should be verified in future work.

In 2004, a field campaign of combined laser scanner measurements and a helicopter flight was done. The project planning, data processing and the results will be published later. The focus of this paper is on the planning of the UAV flights and the UAV system, which were done within this project network.



Figure 1-2: Pinachngo Alto - overview of the settlement area.

2. APPLICATIONS OF UAVS IN PHOTOGRAMMETRY

The main application of UAVs could be defined with observation, maintenance, surveillance, monitoring, remote sensing and security tasks.

In the ISPRS commission V (2004-2008) Working Group 6, the autonomous vehicle navigation will be investigated. Nobody knows which systems already exist for photogrammetric applications, therefore an overview about recent projects will be displayed.

In the last years, more and more applications of UAV-systems in photogrammetry became common. This development can be explained by the spreading of low cost combined GPS/INS-systems, which are necessary to navigate the helicopter with high precision to the predicted acquisition points. Some systems are used without GPS/INS-systems, especially for the capture of roofs for the combination with terrestrial measurements. For the applications using UAVs only and for the reduction of the number of control points, the GPS positioning should reach decimeter accuracy.

Zischinsky et al. (2000) used images taken from a model helicopter partly for the generation of a 3D-model of an historical mill. For the documentation of the building, 82 pictures were taken from the ground and additional 38 images from the helicopter to close the gaps in the model. The small format amateur camera mounted on the helicopter took mainly images of roofs and the courtyard. For the outer orientation of the model 120 control points were determined.

The Yamaha model helicopter is primarily developed and used for agriculture application, like insect pest control of rice paddies, soybeans and wheat. The first system, RCASS, was built in 1980. Later on, in 1990, the helicopter R50 had a payload of 20 kg and a laser-system for height determination. In the year 1997, the type RMAX came out and 3 years later it was equipped with an azimuth and differential GPS sensor system (Yamaha, 2004).

The RMAX UAV system from Yamaha was used as a ground truth measurement system (Hongoh, 2001). Ground truth measurement is used to determine the vegetation coverage. Therefore, the sensor takes images from different viewing angles, which is the most important aspect of bi-directional reflectance measurements.

In the same year a helicopter was used for Chinese fortress measurements. The Japan Miyatsuka Institute of Archaeology wanted to make high-resolution images of this huge fortress side (3 km x 4 km). Normally, foreigners are not allowed to use aeroplanes or helicopters to take aerial images in other countries. The remote controlled helicopter covers none of the both categories and for that reason the UAV-system was used with metric and non-metric cameras.



Figure 2-1: WITAS Unmanned Area Vehicle -Yamaha RMAX Aero Robot.

In 2002, the Yamaha RMAX helicopter was used in photogrammetric flights over two test sites in Sweden, to analyse the accuracy of the GPS/INS for the photogrammetric purposes with manual and autonomous flying modes. The results show that the stability of the camera mounting, the vibrations are caused by the main rotors and the GPS accuracy are the important parts of a UAV-helicopter (Eisenbeiss, 2002 & 2003). These flights were done in co-operation with WITAS –Wallenberg Laboratory for research on Information Technology and Autonomous Systems (Linköping University, Sweden) and the Institute of Photogrammetry and Remote Sensing (TU-Dresden).

At the ISPRS congress 2004 in Istanbul two papers about UAV-helicopters and three about UAV-aircraft were published. The first is a system, which integrates laser scanner and CCD-cameras with GPS/INS data for constructing digital surface model. This system uses a Subaru helicopter with a payload of 100 kg and diameter of the main rotor of 4.8 m. Similar helicopter systems before were classified by mini UAV system. This bigger helicopter is not covered by the micro to medium size UAVs because of the mass of 330 kg. But looking at the range and altitude, the helicopter can be defined as a mini or close range UAV. (Nagai, 2004)

The second presented system is a mini UAV-helicopter, which was used as a photographic system for the acquisition of ancient towers and temple sites. The helicopter should replace high camera tripods and ladder trucks, which are uneconomical in cost and time. The helicopter Hirobo & Eagle 90 has a main rotor diameter of 1.8 m of the main rotor and a payload capability of 8.5 kg. The helicopter took images from the upper part of the temple from all sides. The images of the lower part were taken from the ground. The helicopter could carry different camera systems like miniature (35 mm), medium (6 cm x 4.5 cm) and panorama (6 cm x 12 cm) format cameras and video cameras. A gimbal was designed as a buffer that can absorb noises as well as vibrations. Onboard the system, a small video camera is installed too, which is connected to the ground station to transmit the images to a monitor in real time (Sik, 2004)

The Chinese Academy of Surveying and Mapping develops a mini UAV-aircraft which is used to extract from one image and a 2D GIS database 3D models of buildings. Because of the wind it was difficult to control the vehicle-photographing pose and to take images on the predicted acquisition points. The developers had some problems to obtain stereo images (Wang, 2004).

On the ISPRS congress 2004, also two papers were published about the Pegasus, which is a long endurance UAV system for remote sensing. These kind of systems have the capability to fly long time because solar energy is used as power supply. The system can carry a payload of about 300 kg (Everaerts, 2004).

Some companies already use helicopters (Figure 2-2) with/ without GPS navigation for the production of aerial imagery of single buildings and cities or for documentation of industrial constructions (Helicam 2004, Pollak 2004).



Figure 2-2: UAV-helicopter by Helicam and weControl, Switzerland.

The studies have shown that UAV-systems in photogrammetric applications are at the beginning, even though that the first applications have been accomplished at the end of the seventies of the last century. The potential of these systems, due to their capability to fly nearby the object from different positions and to combine aerial and terrestrial acquisitions, were already pointed out by Wester-Ebbinghaus in 1980. But the problems caused by vibrations of the UAV and the influence of wind and manual controlling of these systems limited their acceptance as photogrammetric measurement platform in the past. Nowadays, even with low cost GPS/INS-systems, UAVs can be navigated with decimetre accuracy and the orientation parameters can be used for navigation, post processing by reducing the number of control points.

In comparison with other mobile mapping systems, the RC-helicopters are not developed to cover large areas and for the use of photogrammetric film based cameras (23 cm x 23 cm). The unmanned helicopter can cover small areas and in particular, it could acquire images easily from all sides of complex buildings (Table 2-1). Also the project costs by the use of RC-helicopters are lower than by the use of aircraft or terrestrial equipment. More information about the state of the art of mobile mapping systems were published in Schwarz, et al. (2004).

System	Equipment			Applications (size and structure)			
	GPS/INS	Laser	Camera	Large areas	Small areas (< 2 – 4 km ²)	Route Mapping	Complex buildings or structures
Aircraft	yes	yes	Film based and Digital	+	-/+	+	-
Helicopter	yes	yes	Digital	-	+	+	-
Terrestrial system (car, train)	yes	yes	Digital	-	-/+	+	-
RC-Helicopter	yes	yes	Digital	-	+	+	+

Table 2-1: Overview of Mobile Mapping Systems (Equipment and applications).

3. DESCRIPTION OF THE HELICOPTER SYSTEM

3.1 UAV Mini Helicopter System

For the photogrammetric recording of Pinchango Alto, we decided to use an UAV-helicopter Copter 1B from Survey-Copter equipped with a GPS/INS stabilised system (Figure 3-1) and a ground control station by weControl.

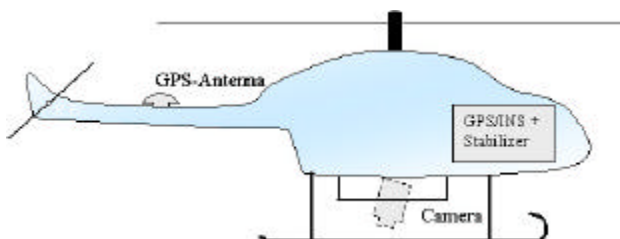


Figure 3-1: Sheme of a remote controlled model helicopter.

Furthermore, for the flights it was necessary to have monitoring software, communication links, flight determination system, ground support and maintenance equipment, power

generation, handling, storage and transport equipment and a video link for monitoring the image overlapping as a manual control. The last point was important, because it was not clear how accurate the predicted points (in and across flight direction) could be flown.

A flight planning system was developed such that the predefined points could be loaded into the controlling system and illustrated on a digital map in the control software viewer. The helicopter position and orientation is displayed in the map, too. Therefore, the operator is able to control its position and orientation (Figure 3-2).

With the controlling software, it is possible to load a flight mission. The stop points for the image acquisitions and the route can be defined and after that, the flying path will be automatically flown.

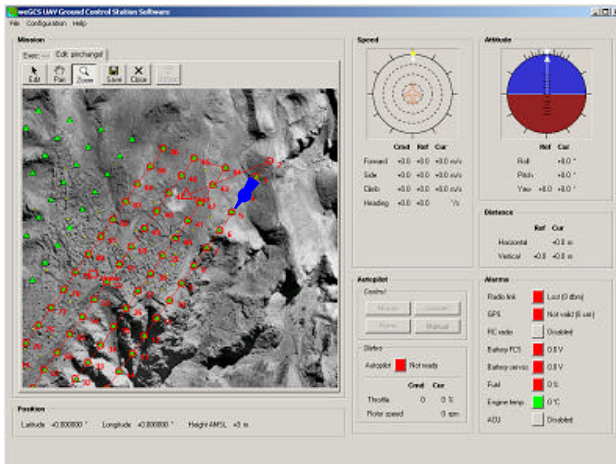


Figure 3-2: WeGCS- Ground Control Station (weControl, 2004) software for the UAV.

A pilot is only needed for starting and landing in dangerous areas like Pinchango Alto and for the support of the UAV. After take off, the operator controls the functionality of the UAV-system through the check buttons (position, heading, radio link, GPS, RC radio, battery). If the predicted point is not correctly reached, the operator can correct the position, the altitude and the yaw angle of the helicopter through commands on the laptop.

With the predefined points, the actual position and a special stabiliser the orientation of the UAV is automatically corrected, even though a light wind force influences the position. The rest vibration of the helicopter can almost eliminated by a special mounting of the camera. Until now, the GPS/INS-system is used for navigation only and not for direct georeferencing. The system's parameters are listed in the following:

Relative positioning accuracy GPS:

- Horizontal: ± 0.5 m
- Vertical: ± 0.3 m

Velocity:

- Forward direction: 20 m/s
- Sideward direction: ± 5 m/s
- Backward direction: 5 m/s
- Vertical Direction: ± 2 m/s
- Vertical turning rate: 30 deg/s

Accelerations:

- Horizontal: 1 m/s^2
- Vertical: 0.5 m/s^2

The maximum possible distance between the ground control station and the helicopter is 1000m in horizontal direction and the maximum flying altitude is 300 m. For safety reasons, the pilot and the operator must see the helicopter. The payload capability of the UAV-helicopter is 8 kg at this time.

3.2 Camera System

We decided to use a Canon D60, D10 and a Rollei 6006 for the image acquisition. The Canon D10/D60 has a CMOS-Sensor with 6.3 Mpixel (3072 x 2048). The camera has also a possibility to save the image with a radiometric resolution of 48 Bit (16 Bit per channel) in RAW-format. Because of their high radiometric resolution and the short time for image saving due to the CMOS-sensor technique, the Canon cameras were available. To reduce the height of the helicopter a lens with a focal length of 14.26 mm was selected to get the required image scale.

The camera system could also be replaced with other digital cameras or medium size analog cameras like Rollei 6006 (Image format 6 cm x 6 cm). For the controlling of sufficient image overlapping, a video camera was installed, which covers the same area like the digital cameras. This video signal was transmitted to the ground control station and displayed on monitor or video glasses.

Due to problems with the forwarding agency we had only two days left for image acquisition in Peru. Therefore, we decided to take images with digital cameras only.

4. FLIGHT PLANNING AND FIRST RESULTS FROM THE FLIGHTS

Before the flights in Peru, some tests were necessary in order to check the system. The UAV-system from Helicam was already used for photo flights in Switzerland, but has never been applied before for photogrammetric flights with a predefined flight path.

The tests in Switzerland showed that the used camera platform was not sufficient for our purposes, because vibrations were not absorbed and the camera could not be aligned straight to the ground. Furthermore, some problems with engine and gas occurred. For Peru, a new platform was built in the way that the camera is directed straight down and the vibrations are reduced to a minimum. The engine and the petrol were changed too.

The test flights showed also, that in the manual mode it is not possible to keep the predefined waypoints. Therefore, all flights were done autonomous, barred from take off and landing. The pilot controlled these manoeuvres.

For the area of Pinchango Alto, an image scale of 1:4000 for the digital images was selected. With the fixed image scale and focal length, the flying height was defined to 56 m above ground. The area of interest was located using an orthophoto (Figure 4-1), which was produced from aerial images with a scale 1:7000 (Gruen et al., 2000). We defined as two areas of interest, due to the lack of time it was impossible to acquire "everything". The area with the best-preserved walls got the priority one (Figure 4-1, blue frame) and the whole settlement (Figure 4-1, red frame) priority two for the image acquisition.

Due to the slop terrain in the area, the absolute flying heights were defined using the orthoimage and an elevation model (DTM generated from the aerial imagery). With the image format of 15 by 22 m on the ground and the image overlapping along and across track of 75 percent, the acquisition points were calculated. All formulas can be found in Warner et al. (1995). All points were set up as stop points. The maximum speed between the points was set to 2 m/s.

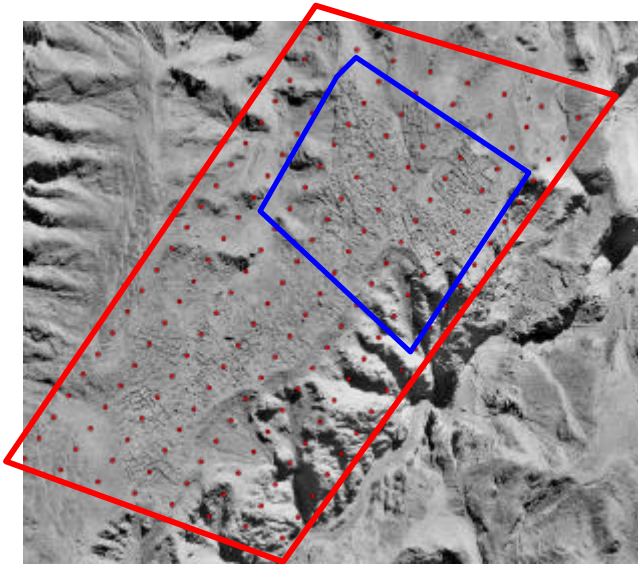


Figure 4-1: Flight planning and defined stop points of the helicopter in Pinchango Alto.

With the used UAV-helicopter system, we could cover 90 percent of the whole area with only 5 image strips and around 100 images. The 3D position of the projection centres could be achieved with an accuracy of 2 to 5 percent of the predicted position. In Figure 4-2 the UAV-helicopter over the settlement in Pinchango Alto is shown.



Figure 4-2: Used UAV-System in Pinchango Alto, Peru.

Using the acquired images, we will produce a DTM, an orthoimage from the whole settlement and derivatives (Figure 4-3).

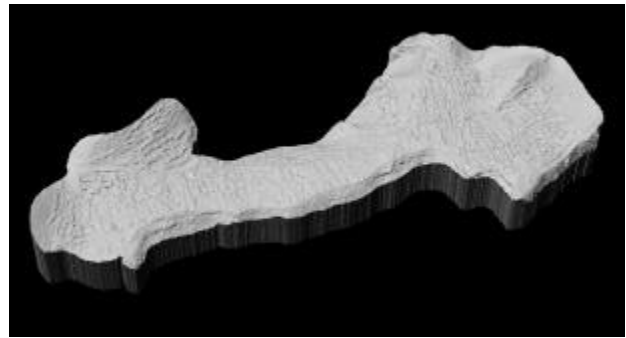


Figure 4-3: 3D-model produced by the company Riegl Laser Measurement Systems.

5. CONCLUSIONS AND FUTURE WORK

Within the project Pinchango Alto we did the first photogrammetric flight over an ancient settlement in Peru using an UAV-mini-helicopter system, which is equipped with a GPS/INS-sensor and a stabiliser. The flight planning and measurements have shown that this UAV-system offers great advantages in cultural heritage recording compared to traditional methods. The RC-helicopter is easy to handle and can fly the predicted flight path even when a light wind is influencing the helicopter. The results also show, that we have to handle the engine problems. The helicopter should have the capability to fly longer than 15 minutes, which requires a bigger tank. The engine power should also be increased, so that the helicopter has the capability to carry a higher payload.

In comparison with other described UAV photogrammetric projects, this helicopter can be used without terrestrial imagery. Because of the stability of the helicopter in air, no problems with image overlapping occurred. Until now, the post processing takes still the same time as the ordinary photogrammetric flights, because of the low accuracy of the GPS/INS-system. In the future we will increase the accuracy and reduce the processing time.

With the data in Pinchango Alto, we plan to produce a 3D-model, which we will compare with the results of laser scanning. We will generate maps of the settlement and produce a virtual 3D-model from both data sets.

Recently, UAV-helicopters in photogrammetry have shown the capability for mobile mapping in close range applications. The main problem of a mini model helicopter is still the vibration of the system, the payload capability and the integration of all sensors.

6. ACKNOWLEDGEMENTS

The author thanks Prof. A. Gruen who gave us the opportunity to realise the laser scanner and model helicopter project in Pinchango Alto, Peru. The author also wants to thank Karsten Lambers and Martin Sauerbier (IGP- ETH Zurich), who supported the planning and realisation of the laser and helicopter measurements in Pinchango Alto. Furthermore, the author is very grateful for the project funding by the NTG project network.

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