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Application of a Newly Developed Visual Navigation System in Humans. First Results

Abstract

A visual navigation system (VN) was developed which uses intraoperatively stored endoscopic images together with their specific 3D-address. A special calibration enables one to recalculate the distortion of the endoscopic images. Several modules (e.g., landmark tracking, virtual back-movement) are offered to the neurosurgeon. The system was tested in 12 human subjects during neuroendoscopic interventions and worked without problems in nearly all cases. The possibilities of digital image navigation can be used especially for control of instrument movement in case of red-out situations or blurred vision. Many further developments of the VN system are possible in order to increase the safety of neuroendoscopic interventions.

Key words

Neuroendoscopy · neuronavigation · image-guided surgery

Introduction

The aim of our study was the development of a navigation system for neuroendoscopy which provides an endoscopic image in situations with loss of vision and which enables operation in parallel to conventional navigation systems working with radiological images (CT or MRI). The system uses intraoperatively stored endoscopic images. The aim of the study was the application of the different developed modules in human subjects during neuroendoscopic interventions.

Materials and Methods

Calibration process

The system's function is linked to the fact that each endoscopic image point can be assigned to a 3D point in the operative field. In general, this is more difficult than it seems to be because the endoscopic image is distorted. In the early stages of our project, an optic calibration was performed to even out the endoscopic distortion. A special modification of the technique of Tsai [1] was used. In practice, this was done using a calibration pattern with rings at equal distances, which could be shifted with a micrometer-screw on a special designed *shunting table*. With the system calibration, the optical position measurement system (OPMS) of the used navigation system was tuned to the endoscope and the camera. This was used in order to visualize landmarks in the camera's field in the correct location. A modification of Longuet-Higgins's method [2] was used.

Surgical procedure

All interventions were performed with a rigid 5.9 mm neuroendoscope (Type Camaert, Wolf, Knittlingen, Germany) armed with LEDs (infrared light-emitting diodes). They were placed

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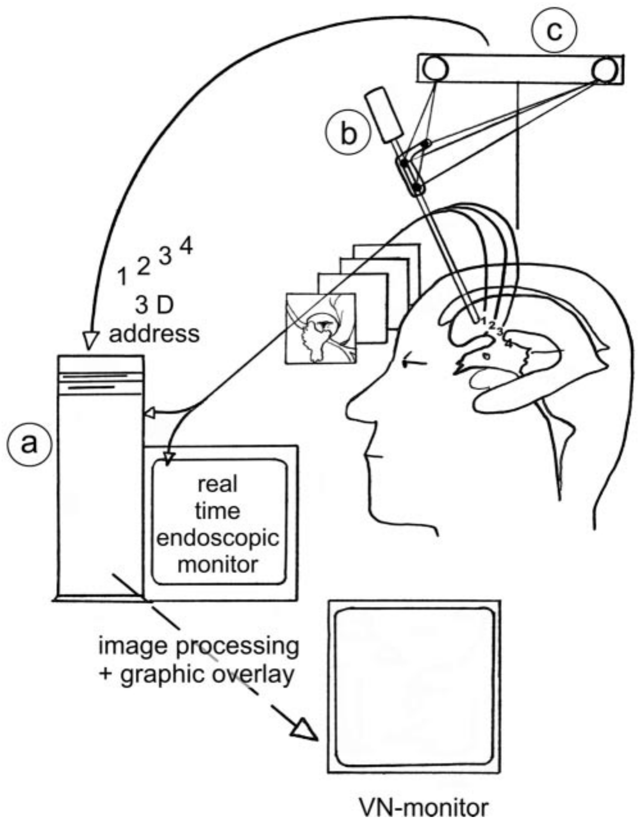

Fig. **1** Construction of the VN systems: **a** PC und VGA monitor with live-display storage up to 16 Hz; **b** rigid endoscope (Wolf, diameter 5.9 mm) with CCD camera; **c** OPMS (Philips), stereocamera system, 3D-measurement, 8 Hz, 1 – 2 mm accuracy.

Table **1** Pathologies and operative procedure

Pathology/Procedure	***N***
aqueductal stenosis/ventriculostomy	7
frontotemporal arachnoid cyst/fenestration	1
unilateral hydrocephalus/with perforation of septum pellucidum	1
intraventricular lymphoma/biopsy	1
tumor cyst (astrocytoma III)/fenestration	1
arachnoid cyst of the posterior fossa/fenestration	1
total	12

18 cm from the instrument's tip so that the position of the endoscope could be determined by the OPMS (optical position measurement system). The endoscopic images were digitalized by a frame grabber (Matrox Meteor) and transferred with their specific 3D position to a personal computer (PC). Specially designed modules enable image processing for navigational purposes. The system is shown in Fig. **1**.

Using the newly developed VN system, 12 patients between the ages of 17 and 92 years were operated on at the Department of Neurosurgery, Ruhr-University Bochum. Table **1** illustrates the pathologies of the operated patients. In three cases the system was used in combination with the Easy-Guide navigation system (Philips).

Description of software modules

The module *alarm system* is a standstill control of the endoscopic image. When the instruments are introduced during neuroendoscopy, the endoscope is sometimes fixed to a holding device, which allows observation of one special anatomic area. A dislocation of the holding device is extremely dangerous in this phase of operation. The module controls the endoscopic image. In case of displacement of the endoscopic image, it gives off an acoustic alarm. It is programmed such that natural pulsations, such as plexus chororideus, do not activate the system.

The module *landmark tracking* follows up to 6 landmarks (theoretically more) also outside the actual visual field. Marking can be done either with a single computer mouse click and automatic tracking within slight minimal endoscopic movement or with several (up to three) clicks from different endoscopic positions or depths.

The *module measurement* is evolved from the module landmark tracking: If two landmarks of the endoscopic image are marked, the system calculates automatically the correct distance in mm. (This module was previously tested in a bath of Ringer solution in the laboratory.)

The *module virtual back-movement* gives the surgeon a black and white endoscopic image inside the operative field. This image is generated from the so-called virtual map of the computer. All images were stored every half second together with an exact 3D address. If one point is passed several times, the actual image is stored and the former image is deleted. A red alarm signal informs the surgeon if there are suitable virtual images or not. If the signal rises, this indicates that the surgeon is moving to a new area. Meaning an area he was never seen before.

During loss of visualization, this system enables a safe back-movement through the foramen Monro and gives the possibility for coagulation by the guidance of the graphic overlay of the coagulation fiber [9].

Protocol of module testing

The module tests were allowed by the Ethic commission of the Ruhr-University Bochum (No. 844). The modules were tested during normal neurosurgical interventions. The storing of endoscopic images together with 3D addresses is initiated directly after introduction of the endoscope into the brain. Once the storing process is started, it is automatic. The module's alarm system and measurement were tested when the endoscope reached a stable operative position, for example, in ventriculostomy measurement of the opening is performed. Quality of the measurement was controlled in situ by comparing the measured distance with the diameter of a 2-mm coagulation fiber. Once set, the landmarks are tracked during final inspection of the anatomic field always outside of the operative area and back to it. If a set landmark was found back exactly the quality of landmark was protocoled as good. The module virtual back-movement was always tested at the end of the operation. The neurosurgeon could not see the endoscopic monitor but the screen of the VN computer. An engineer only controlled the endoscopic monitor. The sur-

Table **2** Module tests

Patient's age (years), sex	*Alarm system*	*Measurement*	*Landmark tracking*	*Virtual back-movement*
36, f	safe function	safe	safe function	trouble free function
72, f	not tested	not possible	not possible, wrong connection between camera and endoscope	trouble free function
37, m	during pulsation reduction of sensitivity	safe	safe function, support of neurosurgeon during failure of the Easy Guide system	trouble free function
60, f	2 × false alarm due to pulsations afterwards safe	measurement possible	tracking possible (connection between camera and endoscope not optimal)	trouble free function
92, m	safe function	not possible	not possible, wrong connection between camera and endoscope	trouble free function
29, f	not tested	safe	after several attempts safe function	malfunction, hardware problem
78, m	not tested	safe	safe function	malfunction hardware problem
38, f	safe function	safe	safe function	trouble free function
48, f	not tested	safe	safe function	trouble free function
68, f	safe function	safe	safe function	trouble free function
58, m	not tested	safe	safe function	trouble free function
34, m	not tested	safe	safe function	trouble free function

geon moved the endoscope back to the burr hole using only virtual images. The procedure was stopped if unwanted contact to the anatomic cavity was observed. This last step of the experiment was extensively trained in anatomic cadavers [4].

Results

Results of the study are given in Table **2**. The module alarm system was only tested in 6 patients. In four cases, the function was reliable and in two patients there was a wrong alarm due to strong, not rhythmic pulsations. In 10 cases, the module's landmark tracking and virtual back-movement were working without problems.

Fig. **2** gives an example of the virtual map obtained during third ventriculostomy.

In 2 cases, the modules showed malfunction. The analysis pointed to a disturbed hardware access produced by damage caused by transport of the system. The module measurement showed correct function in 9 patients. Fig. **3** gives an example of the measurement of a ventriculostomy. In 3 cases, the endoscope was not correctly connected to the camera during sterile draping. Therefore, calibration was disrupted because of massive adjustment of the focusing screw. Fig. **4** shows the view of the foramen of Monro in this case with an intraventricular lymphoma.

However, after standardized draping and connection of the endoscope, this problem did not occur anymore.

In the case of a 37-year-old patient, who suffered from an astrocytoma (WHO III) a clear clinical advantage was found (Fig. **5**). During operation, the parallel used radiological navigation system failed. By inspecting the tumor cyst the optimal fenestration point could be marked and found again later using landmark tracking, even though dulling of the endoscopic vision occurred.

Discussion

In 1995 Kowdley [5] described the future possibilities of endoscopy using the example of gastroenterology. Beside stereoscopy and vital staining of distinct structures he saw digital image processing as a major development. Nevertheless, digital image processing in endoscopy was only used sporadically, e.g., for image storing and documentation in urology [6] and for optic quality enhancement of the image of flexible endoscopes with so-called digital filters [7] reducing the typical honeycombed form of the image. Another interesting development for the improvement of endoscopic depiction can be found in zoom videoendoscopy [8], a method which enables the surgeon to enlarge the chosen image part 100 times for ultrastructural analysis. A navigation system for sinus surgery in otorhinolaryngology was developed by Gunkel and Freisinger [9]. In this so-called ARTMA-system, graphic overlays inside the normal videoendoscopic image are offered to the surgeon, although the distorted endoscopic images are not calibrated, thus making the development of digital modules impossible. Neuroendoscopic conventional navigation with CT or MR images has been used since the end of the 1990s [10–12], since then it is clinical routine in many departments.

Despite the limited amount of operated patients, the present clinical study could demonstrate that the use of digital navigation modules in neuroendoscopic intervention is possible and helpful.

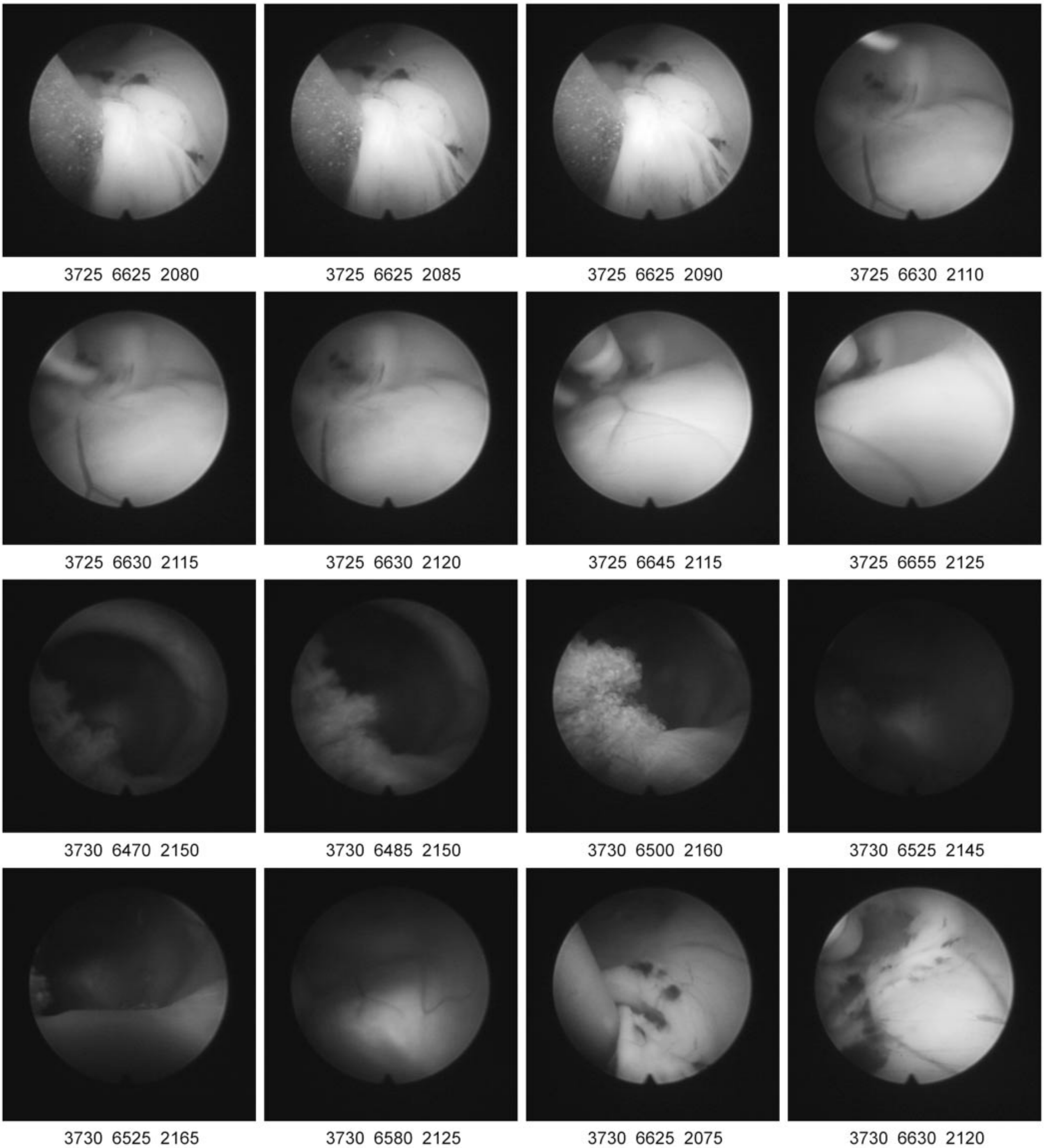

Fig. **2** Virtual map obtained during third ventriculostomy.

The usefulness of different modules was quite different during clinical evaluation. The module alarm system, for example, was only tested in 6 patients. After the calibration problem was solved, the modules of the developed VN system are suitable to support the surgeon: not only optimized documentation (e.g., measurement and screenshot function), but also the security of endoscopic interventions can be increased (e.g., alarm system, landmark tracking, virtual back-movement).

One disadvantage up to now is the necessity for a third person (engineer or physician) who will run the computer. An improved user surface would probably increase the practicability of the system and enable the assistant or surgeon himself to operate the computer. A sterile draped computer mouse or the use of a touch screen monitor are possible solutions.

In future a better integration of the VN system into conventional navigation systems is planned. Also a great challenge is the cam-

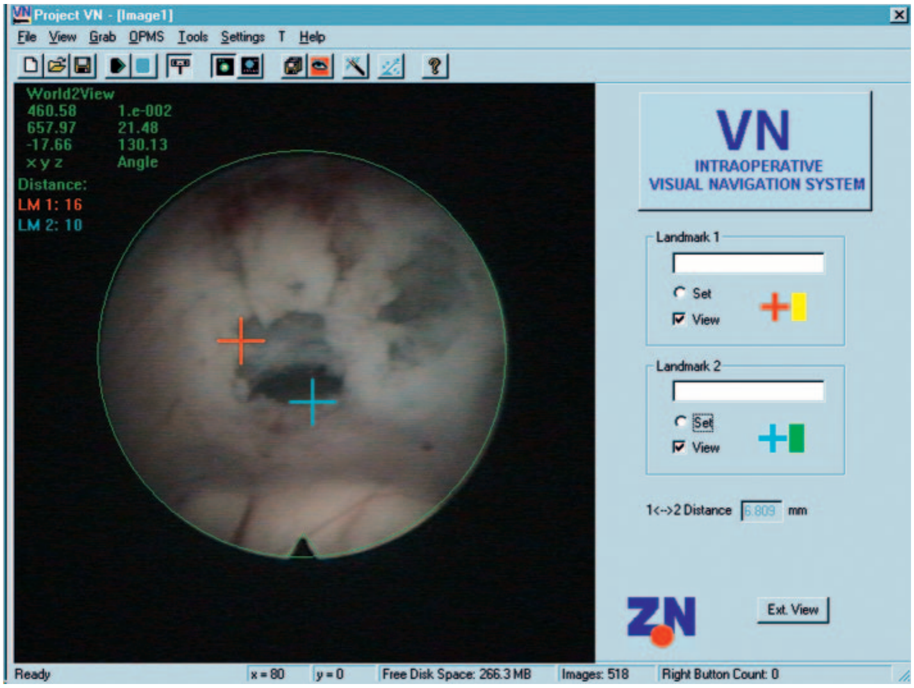

Fig. **3** Measurement of ventriculostomy size in a case with a very thick floor of the third ventricle.

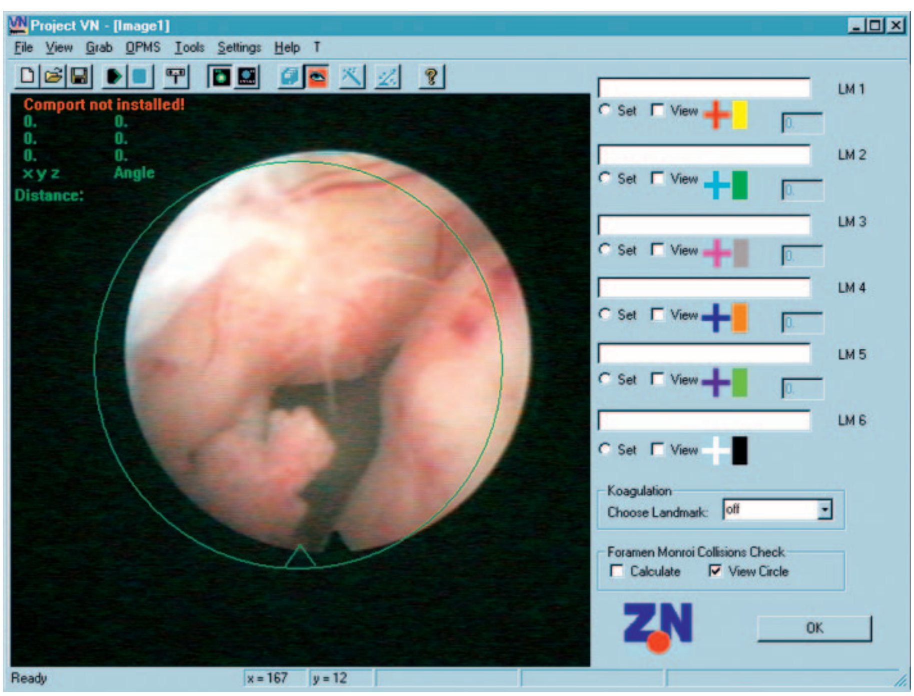

Fig. **4** Endoscopic image in a case of an intraventricular lymphoma: view to the foramen of Monro. Typical VN user surface with the possibility of tracking 6 different landmarks simultaneously.

era calibration systems from different manufacturers. The use of the developed module for virtual coagulation [3] was not necessary in the present 12 cases. However, it can be used hopefully in seldom situations if selected clinical cases occur.

Another application would be the combination with radiological virtual endoscopy. An interesting tasks seems to be the integration of radiologically reconstructed 3D-images obtained from spiral CT or MR [13] into intraoperatively stored, previously seen images of the VN system. Kawamata et al. [14] developed an endoscopic augmented reality navigation system for endonasal transsphenoidal surgery to treat pituitary tumors. In this system, anatomic three-dimensional virtual images of the tumor and nearby anatomic structures (including the internal carotid arteries, sphenoid sinuses and optic nerves) were superimposed on real time endoscopic images.

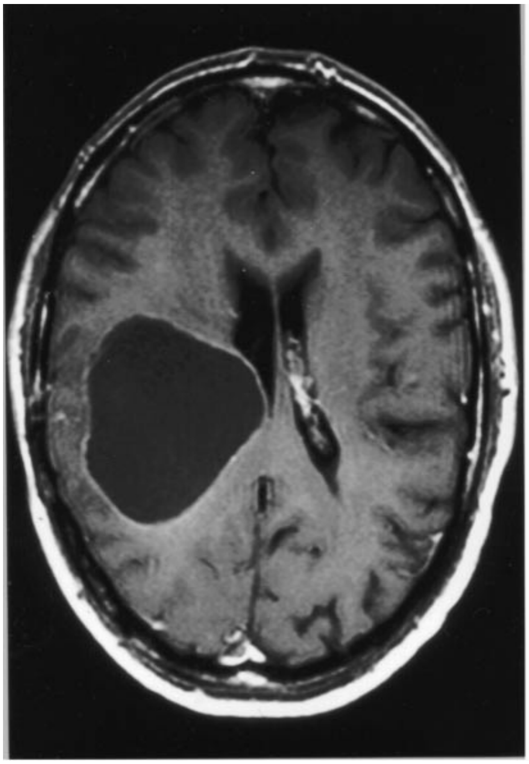

Fig. **5** Tumor cyst after resection of an astrocytoma (WHO III). MRI prior to the planned endoscopic cystoventriculostomy with the VN system.

In the near future, the design of other modules, e.g., virtual image enlargement, is also planned. The use of image processing systems, working independently from radiological information, will be an important part of neurosurgical work in the future.

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