Automation for consistent scan quality

**Philips SmartExam** Total exam automation improves efficiency, consistency and reproducibility of MR studies

Following the introduction of the ExamCards – which provide automated MR protocol execution and automatic processing – Philips has launched SmartExam. With anatomy recognition built on the foundation of the ExamCards, SmartExam completes the automation loop by providing automatic exam planning. This document describes the principles of SmartExam and clinical results in brain imaging.

SmartExam is available for all new Philips MR systems, and is also available as an upgrade for most Philips MR systems installed since 1994. SmartExam delivers consistency in scan quality, in each and every patient, without delaying any of the scans. This provides the radiologist with identical results in each and every patient, irrespective of the initial position of the patient within the MR system, or experience of the operator. Furthermore, the consistency improves accuracy in the analysis of follow up MR scans.

A Philips-exclusive technology, SmartExam is making a major impact on MR department efficiency and scan quality.
SmartExam: daily clinical routine

In “conventional” clinical MRI examinations, the precise geometry of diagnostic scans is defined in an initial planning phase. Based on a preliminary survey scan, the operator positions the scan volumes (off-center, axes, FOV) in relation to patient anatomy in a dedicated user interface at the scanner console. Multiple scans are often planned, and scanning will only proceed when geometries have been identified.

With SmartExam, patient positioning will be analyzed and used to plan geometries automatically, requiring no interaction whatsoever by the operator. The normal survey is replaced by a fast 3D survey, performed in the background, which is used to accurately analyze the position of the patient. The geometries in such a “smart” ExamCard are known from previous sessions in which the operator still performed manual planning.

SmartExam is the combination of automatically identified patient position and validated hospital preferred geometries, creating automated and consistent planning. Consequently, SmartExam runs totally automatically, producing consistent planning results for normal slice geometries, rest-slabs, shim volumes, and spectroscopy volumes and slices, according to the preferred settings of the hospital. Scanning a patient in the most advanced manner possible can now be done at the touch of a single button.

In 2003, the research effort was robust enough and was integrated with the ExamCards scanning environment. This resulted in a robust automated recognition and scanning strategy for brain scans, the most common routine application today. A detailed description of their results was published in 2006 [1]. The method of landmark detection method includes multiple steps:

- Basic registration with a standard model
- Identification of the mid-sagittal plane
- Matching brain landmarks
- Outlier detection

First, a global match is made using intensity-based registration. This match is refined by identifying anatomical structures in the brain. An important step is identification of the mid-sagittal plane, which conceptually divides the left and right brain hemispheres, and this slice will define a number of the essential landmarks.

“SmartExam worked so well that we almost forgot we were using it. After a short while, we realized that this tool is very robust and doesn’t need supervision.”

SmartExam: based on landmark detection

The core of SmartExam is based on landmark detection in MRI data, developed by a team of Philips research scientists. Such a system has to deal with a wide range of variations in patient position, shape of anatomy and pathologies. Normal 3D rigid-body registration algorithms will often not work in post-surgical scanning, for patients with a large neoplasm or for pediatric patients. In a clinical situation, the strategy must be robust to account for major deviations from normal anatomy.

Extracted locations of the mid-sagittal plane (left, center) and anatomical landmarks within the plane.

Identification of positioning in a patient with severe pathology (Image by courtesy of St. Jan’s Hospital, Bruges, Belgium).
ExamCards: The foundation of SmartExam

This mid-sagittal plane is reformatted from the 3D survey, and an active shape model is then applied to estimate the exact positions landmarks of important anatomical structures.

An advanced system of so-called outlier detection verifies whether landmark items of specific patients should be disregarded, preventing bias in “abnormal” situations. In other words, when a landmark deviates by a large amount it will not be used in the further analysis. This combined landmark detection method plus outlier detection algorithm — all included in SmartExam — will guarantee correct identification of patient positioning, even in cases of very serious pathology [2].

Bonn’s Dr. Willinek credits the robustness of the SmartExam anatomy recognition algorithm in unerringly locating the proper slices between patients: “I anticipated that SmartExam would function accurately if we used normal brains, but I was positively surprised that it also works well with patients who have severe pathology,” he says. “SmartExam works even in cases where pathology has shifted the geometrically crucial midline. It also works in stroke cases and in pediatric studies in which congenital malformations present in hypoplasia of midline structures.”

Validating Geometries

Smart ExamCards are exam cards that combine the use of a 3D survey, and have smart geometries. The survey is used to extract landmarks, determining the position of the patient. The smart geometries are geometries known with respect to the position of the patient (or more exactly, known with respect to the landmarks).

ExamCards contain a well-structured list of scans and processing steps that compose a multi-sequence examination, along with icons indicating scan status, actions needed, and upcoming acquisitions. ExamCards are complete, ready-to-use scan protocols that — like the automatic scan planning component of SmartExam — run completely autonomously at the touch of a button, and perform various types of processing according to hospital preferences, requiring no supervision.

Since ExamCards became available on Achieva, Intera R11 and Panorama HFO systems in 2004, hundreds of Philips MR users have downloaded and uploaded ExamCards to and from their MR systems via the Internet and Philips’ NetForum Community. Many clinical sites are benefiting by converting all applicable protocols into ExamCards. Furthermore, ExamCards reduce training requirements and make it easy to share protocols with colleagues.

For a routine examination, the operator simply selects the appropriate ExamCard, and all scans for the study immediately appear in the Exam window, enabling the complete clinical study to be started at the touch of a button. The ease of scan preparation using ExamCards simplifies the process, even for inexperienced operators, helping to prevent errors and safeguarding the preferences of each hospital or individual radiologist.

The free Internet-enabled NetForum Community (netforum.medical.philips.com) strengthens the concept because it facilitates downloading of best-practice ExamCards directly into a department’s MR scanner, permitting users to benefit from others’ experience. A downloaded ExamCard can be used in its original form or customized to suit another preference or clinical need.
Geometries become smart geometries with one simple mouse click. At that moment the geometry will become a “validating” smart geometry. During the first few patients the operator will perform scanning in the normal conventional manner, planning scans manually in all patients according to individual preference. In these patients, the system will closely follow the definition of the planning phase, thereby validating this geometry by comparing the manually chosen geometry to the position of the patient (i.e. landmarks) in each and every patient. In the second patient SmartExam will already propose a geometry setting. After 10 patients, SmartExam will turn the “validating” smart geometry into a “validated” smart geometry, making the ExamCard fully automatic.

With SmartExam the operator remains in control: it is always possible to modify the planning given by SmartExam, e.g. to adapt the applied geometry. In such a case the new manually planned position will be added to the database of that smart geometry, if that is what the operator wants, improving planning accuracy for the future. In this sense SmartExam is an adaptive system: it identifies requirements during normal operation by a technologist. SmartExam is the autopilot system for MR.

A smart geometry can be validated and/or used in multiple ExamCards – yielding consistency of geometries over the full set of ExamCards being applied in a given hospital. Of course, multiple smart geometries may be established on any site. The knowledge of all smart geometries of SmartExam resides on a database in the scanner. An important aspect is that this database can be exported from the system and imported – regardless of field strength – to other scanners. The preferred settings of one scanner are then instantly available and ready-to-use on a new system, in order to provide the same consistent scanning. In most cases, this sharing takes place between scanners in the same institution, to account for the individual sites’ planning variations and preferences. However, it is not limited to one hospital but can also be transferred to other sites. For example, a SmartExamCard and a validated database can be used to perform consistent scanning in multi-center trials.

Nancy Dudek, Lead MR Technologist at the University of Michigan Health Center, has described their current set of validated Smart geometries. The list includes transverse, coronal and axial settings for the routine brain, the routine pediatric brain, temporal lobe epilepsy, pituitary, various cranial nerves etc. All in all, SmartExam is used in 100% of their brain scanning, thus providing standardized and automated brain scanning even in the more difficult geometry settings.

**Benefits of SmartExam**
SmartExam delivers consistency in scan quality, in each and every patient, without delaying any of the scans. This consistency of planning will provide the radiologist with identical planning in each and every patient, irrespective of the initial position of the patient within the MR system, or experience of the operator.

“SmartExam gives us consistency.”

“SmartExam gives us consistency – both in follow-up exams of the same patient as well as consistency between different patients. We are used to looking at pathologies in a certain way,” says University of Bonn radiologist, Winfried Willinek, M.D. “If the angulation differs between patients, then making a diagnosis is sometimes challenging. Consistency is also important in-house research studies and will be a great asset in multi-center studies when more sites acquire SmartExam.”

Proof of this consistency was obtained in a small study, showing that SmartExam is as consistent or better as the best possible operator. It appeared that experienced operators were generally accurate in planning angulations around the FH or AP axis, while angulations around the RL axis, for example to align transverse slices along the corpus callosum, were much more variable. Planning by SmartExam much reduced this variability.

“Having exactly the same slice positioning can be a definite advantage in monitoring progressive diseases such MS.” says Dr. Stefan Sunaert, M.D., Professor of Radiology at Gasthuisberg University Hospital (Leuven, Belgium). “There are strict WHO criteria for Multiple Sclerosis (MS), specifying at least two lesions in white matter to reach a definitive diagnosis,” he continues. “Counting MS lesions is critical in the initial diagnosis and for the follow-up study during MS progression. Unfortunately, the clinician might report four lesions in the first study, while six months later he may see only three, making him wonder what happened. He realizes that this can be caused by a small variation in inclination, making him miss one lesion. But then in the next scan he suddenly sees five. Subsequently, he thinks, ‘Did I miss one last time? Is there progression or not?’ The variation in lesion count presents a dilemma”

With SmartExam, Dr. Sunaert notes, when clinicians see an apparent new lesion in a follow-up study, they can be confident because the slices appear to be in exactly the same locations anatomically over a period of six months. The SmartExam strategy also is excellent when compared with the present method of registering images of successive scans in a post hoc manner, which is time-consuming and costly. “Acquiring exactly the same images or the same orientation of the images in different exams is free with SmartExam right at the acquisition,” Dr. Sunaert says.
“We’ve performed over 1,000 brain scans using SmartExam,” says Robert Smith, MRI Supervisor at Saint Barnabas Ambulatory Care Center (Livingston, NJ, USA), “SmartExam easily enables identical scanning parameters and slice positioning – even multiple angulations – for the patient’s follow-up scan. This kind of reproducibility is a clear advantage, because it takes away the underlying worry that variable positioning may influence the reading/diagnosis in follow-up scanning”

Efficiency of scanning and reporting images is crucial in the active world of radiology because of budget constraints, higher costs, and larger range of imaging capabilities. It is not easily accepted that a scanner is not running a sequence, or that patients have to return to the imaging department because of initial failure.

“Fully Automated Examination greatly improves multi-tasking in our MR department,” says Renate Bloemer, Chief Technologist at the University of Bonn, which runs SmartExam on its Achieva 3.0T system and was the first SmartExam test site. “While SmartExam is planning the study, I can focus on the preparation of the next patient, perform some of the more complex processing at the console, or deal with administration issues. Clearly, my productivity has increased.”

Often, the frenetic pace of the MR department does not easily facilitate dealing with patient record documentation, a task that technologists typically have to squeeze in between patients. According to MRI technologist Mercedes Pereyra at St. Luke’s Episcopal Hospital (SLEH, Houston, Texas, USA): “We now have the luxury of doing paperwork while SmartExam plans and scans automatically.”

Clinical users find that the use of SmartExam boosts MR workflow because no time is wasted as scanning proceeds immediately after the survey. At the Maggiore della Carità Hospital (Novara, Italy) a reduction of scan-time by 30% was found in a study of 400 patients (see insert).

“Full Automated Examination greatly improves multi-tasking in our MR department,”

“We found an average reduction in examination time of 5.2 minutes, which translates into a 30% decrease in exam time,” says Allesandro Carriero, M.D., Professor of Radiology at Amedo Avogadro Eastern Piemonte University (Novara, Italy), in Maggiore’s Department of Diagnostic and Interventional Radiology. “With SmartExam, examinations are now less dependent on operator skills and subjective interpretation. And, there is no need to review images before proceeding with the examination. It also dramatically decreases the training time required for each technologist to become an independent user.”

Maggiore’s Marco Di Terlizzi, M.D. and Technologist Gerardo Di Nardo were instrumental in the study.

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Technologist at the University of Michigan Health Center, which operates SmartExam on its Achieva 3.0T system. “Before SmartExam, technologists needed to focus virtually their complete attention on planning slice positions, and tended to avoid distractions,” she says. “Most patients like it if you talk to them, it makes them more comfortable. SmartExam enables technologists to develop a rapport with patients.”

Identical slices can be obtained regardless of patient positioning. In this patient follow-up scanning was performed using SmartExam. Despite the different initial head position the axial T2 images were identically positioned, and the MS lesions were located in the same slice, and of the exact same size (Images by courtesy of Bonn University Hospital, Germany).

Part of the efficiency improvement does not relate to scanning itself, but to the improved comparison possibilities for analyzing follow-up scans. The progression of neurodegenerative diseases is a key factor in gauging the patient’s condition. The ability of SmartExam to precisely replicate slice positions in successive scans of the same patient has proven very useful, according to Professor Sunaert.

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“SmartExam has also been a huge advantage with regard to technologist training,” says St. Barnabas’s Robert Smith, “Most technologists are able to work the controls by using a simple click and drag method. My part-time and weekend technologists are now able to consistently produce the quality of work our physicians demand”.
Example of automated vertebrae numbering (left) and automated transverse planning (right) in spine studies.

**SmartExam Outlook**

It is a Philips’ promise to deliver advanced systems that are nevertheless easy to operate. SmartExam is a Philips Unique feature: it combines advanced technology and provides ease of use in MR examinations. Philips’ plans for SmartExam and ExamCards do not stop at brain examination, but aim at improved scanning and analysis in further applications.

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SmartExam for knee studies was introduced early 2007, while SmartExam for spine and shoulder studies will be available in 2008 as the next step towards providing SmartExam for all applications.

**References**


