Application

2015-04-09

2015-05639	Heyden, Anders	NT-14

Information about applicant

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Information about application

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Project title (english): Visual SLAM based on Planar Homographies

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Keywords: SLAM, Homographies, Minimal Solutions, Optimization, Sensor Fusion

Funds applied for

Year:	2016	2017	2018	2019
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Descriptive data

Project info

Project title (Swedish)*

Visuell SLAM baserad på plana homografier

Project title (English)*

Visual SLAM based on Planar Homographies

Abstract (English)*

This project deals with the problem of producing a map and navigating in an unknown environment based on visual sensors mounted on a robot and facing down towards the ground. It is assumed that the robot is moving on a planar surface and that the surface contains some kind of structure that is visible in the images. This is an important special case of the general SLAM (Simultaneous Localization And Mapping) problem, that deals with the problem of reconstructing and navigating in a three-dimensional environment. However, in a lot of cases the robot is restricted to a planar motion and this could be used to develop a more robust and accurate SLAM system. One important aspect of SLAM-systems is that the relation between the robot coordinate system and the camera coordinate system needs to be determined, the so called hand-eye calibration. We will develop automatic methods for hand-eye calibration based on so called minimal solvers, that are both robust and accurate. Another problem we will deal with is the possibility to include other sensors and combine them with the information obtained from the visual sensor, so called sensor fusion.

Popular scientific description (Swedish)*

Datorseende handlar om att undersöka hur den information man får från digitala kameror kan användas i olika applikationer och att förstå principerna bakom seende system. Exempel på applikationer är självgående fordon, visuella sensorer i robotik och beräkning av ett objekts tre-dimensionella form. Ett av de mest centrala problemet inom datorseende är struktur- och rörelse-skattning, d.v.s. att beräkna både kamerans rörelse och scenens struktur utifrån en bildsekvens. Detta problem studeras också inom robotik och reglerteknik och brukar då kallas SLAM (Simultaneous Localization And Mapping; Samtidig lokalisering och kartering).

Traditionellt har man studerat struktur- och rörelse-problemet då antingen scenen/objeket är stationärt eller kameran är stationär. Då kan man beräkna den relativa rörelsen mellan objektet och kameran och objektets tre-dimensionella struktur. Algoritmerna är av två olika typer; antingen s.k. off-line algoritmer som körs på alla bilder på en gång, eller s.k. on-line (rekursiva) algoritmer som uppdaterar skattningarna var gång en ny bild finns tillgänglig. Den förra typen ger mycket exakta resultat, men tar ofta lång tid att köra. Den senare typen lämpar sig för applikationer då man inte kan vänta tills alla bilder är tagna.

Projektet går ut på att utveckla ett komplett SLAM-system som kan användas då roboten rör sig på en plan yta, till exempel ett golv. En kamera monteras riktad ner mot golvet och tar bilder medan roboten förflyttar sig. Vi kommer att utveckla algoritmer för att lösa det s.k. hand-öga-problemet, dvs den geometriska relationen mellan kameran och roboten och algoritmer för att bygga upp en karta över hela golvytan, samt för att kunna navigera med hjälp av kartan. Vi kommer också att utveckla metoder för att kunna använda andra typer av sensorer, som till exempel dödräkning, gyroskop och tröghetsnavigering.

En viktig aspekt för den här typen av system är att de är robusta och kan fungera utan att någon behöver rätta till fel som ofrånkomligen uppkommer. Vi kommer att använda etablerade metoder för att uppnå robusthet, vilka bygger på att man kan lösa s.k. minimala fall. Dessa uppkommer när man bara använder precis så mycket information som behövs för att få ut en eller flera lösningar på ett problem. Vi kommer att använda nyligen utvecklade tekniker för att lösa system av polynomekvationer för att analysera dessa minimala fall.

Vi kommer att bygga en demonstrator med hjälp av ett samarbete med institutionen för reglerteknik där vi kommer att använda en av deras robotplattformar.

De resultat som kommer fram inom projektet kommer framför allt att publiceras i internationella tidskrifter och presenteras vid internationella konferenser. Vi kommer även att skriva minst en populärvetenskaplig artikel som beskriver forskningen inom projektet.

Det finns många tillämpningar på användningen av dynamiska modeller i struktur- och rörelse-skattning, till exempel självgående fordon, robotar bestyckade med kameror, visuell övervakning m.m.

Project period

Number of project years*

4

Calculated project time*

2016-01-01 - 2019-12-31

Classifications

Select a minimum of one and a maximum of three SCB-codes in order of priority.

Select the SCB-code in three levels and then click the lower plus-button to save your selection.

SCB-codes*	2. Teknik > 202. Elektroteknik och elektronik > 20201. Robotteknik och automation 2. Teknik > 202. Elektroteknik och elektronik > 20202. Reglerteknik 1. Naturvetenskap > 101. Matematik > 10102. Geometri

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Enter a minimum of three, and up to five, short keywords that describe your project.

Keyword 1*

SLAM

Keyword 2*

Homographies

Keyword 3*

Minimal Solutions

Keyword 4

Optimization

Keyword 5

Sensor Fusion

Ethical considerations

Specify any ethical issues that the project (or equivalent) raises, and describe how they will be addressed in your research. Also indicate the specific considerations that might be relevant to your application.

Reporting of ethical considerations*

Vi kan inte förutse några etiska överväganden som skulle kunna uppstå i projektet.

The project includes handling of personal data

No

The project includes animal experiments

No

Account of experiments on humans

No

Research plan

A: Research Program
Visual SLAM based on Planar Homographies

Purpose and Aims

This project deals with the problem of producing a map and navigating in an unknown environment based on visual sensors mounted on a robot and facing down towards the ground. It is assumed that the robot is moving on a planar surface and that the surface contains some kind of structure that is visible in the images. This is an important special case of the general *SLAM* (Simultaneous Localization and Mapping) problem, that deals with the problem of reconstructing and navigating in a three-dimensional environment. However, in a lot of cases (except for flying robots, e.g. hydrocopters) the robot is restricted to a planar motion. One important aspect of SLAM-systems is that the relation between the robot coordinate system and the camera coordinate system needs to be determined, the so called *Hand-eye calibration*. Another problem we will deal with is the possibility to include other sensors and combine them with the information obtained from the visual sensor, so called *sensor fusion*.

There are several advantages of using a camera facing down at the floor:

- The problem of dealing with occlusions disappear. Usually there is nothing between the camera and the ground floor occluding the images.
- The complexity is reduced compared to general SLAM where a more general motion and a more general scene structure has to be dealt with.
- The map will be much simpler and can be represented by one single large image.

There are also several applications where methods developed within this area are useful, e.g. robots in supermarkets and for elderly care.

The proposed project is multi-disciplinary, involving elements from applied mathematics, computer vision, automatic control theory as well as mathematical statistics.

The main goal of the proposed project is to investigate, develop and analyze algorithms for simultaneous lcocalization and mapping, including calibration of crucial parameters, in the case of planar motion and a planar scene.

More specifically, the following sub-goals will lead to the overall goal.

- Development and analysis of on-line hand-eye calibration methods that are both efficient, robust and can adapt to changes in the calibration parameters.
- Development and analysis of motion estimation methods based on estimated homographies between pairs of images.
- Development and analysis of efficient methods for building maps, including loop closing techniques and develop methods for navigation based on these maps.
- Investigate and develop methods for sensor fusion together with other sensors such as dead reckoning, gyroscopes and inertial sensors.

We will also develop a demonstrator that will show the potential with plane based SLAM. We have close connections to the department of automatic control and will use one of their robots for this purpose.

Summary of the Field

Computer vision is a rapidly evolving research area, that aims at implementing different aspects of the human visual system in artificial form, and even enhancing functionality with superior three-dimensional reconstructions. Another important line of research is to develop algorithms for fast on-line (e.g. based on filtering techniques) methods for processing visual input, which is of particular importance for autonomous systems. One of the main problems in computer vision is the so called structure and motion problem (S&M), which is the problem of estimating both the motion of the camera and the structure of the scene from only the individual images in the sequence. This problem can be treated in several different settings, depending on the a priori information about the camera calibration parameters, the motion of the camera and the structure of the scene, see [15] or [35] for an overview of these problems. Traditionally, the S&M problem has been solved by assuming either a stationary object or a stationary scene and pre-calibrated cameras and off-line calculations, which is closely related to the field of photogrammetry. However, recent research has shown a tight connection between SLAM (Simultaneous Localization And Mapping) and on-line structure and motion estimation, so called visual SLAM.

The first step in a S&M algorithm is to extract and track features in the image sequence in order to find corresponding points. It is necessary to use robust algorithms that are able to deal with outliers and false matches, cf. [37]. After obtaining a consistent set of features, there are basically two different approaches to solve the S&M problem. The first is to use a batch algorithm, usually involving several steps, e.g. estimation of multiple view tensors [37] or iterative factorization, projective reconstruction, Euclidean upgrade (auto-calibration) [29] and bundle adjustment [39]. The other approach is to use filtration based techniques, so called on-line methods, cf. [1], [30]. In this case the parameterization turns out to be crucial, cf. [30].

During the last ten years, several researchers have treated the problem of simultaneously calibrating the cameras and solving the S&M problem, so called auto-calibration. For instance, it has been shown that knowing only one intrinsic parameter (focal length, principal point, skew or aspect ratio) or even only knowing that one parameter is unchanged during the sequence makes it possible to do auto-calibration, assuming a sufficiently general motion of the camera, cf. [29], [19]. However, no such methods exists for on-line approaches, except for ad-hoc methods based on minimizing some error function over all free parameters.

Problems might arise when the camera motion is restricted in some way, depending on the constraints used for the intrinsic parameters. These insufficient motions have been termed critical motions, cf. [21, 34]. The corresponding problem for on-line methods leads to the concept of *persistent excitation*, which is well known in automatic control theory, cf. [5].

The standard S&M problem for un-calibrated cameras has in the discrete case been treated successfully using so called multi-linear matching constraints or multi-focal tensors, cf. [16], [15]. In the continuous case, where the input data is considered as a continuous stream of images, a continuous form of the epipolar constraint can be used to solve the S&M problem, cf. [26]. Another approach, introducing the so called continuous time matching constraints, can be found in [18]. However, these continuous-case methods are all highly non-linear and very sensitive to noise. Another approach is to combine the discrete and continuous approach, leading to so called hybrid motion constraints, see [38] for an early attempt and [17] for recent developments.

There have been some successful applications of dynamic systems in computer vision. For instance dynamic models for the camera motion and the development of on-line filtering techniques in this case have been studied in [32] and [33]. On-line structure and motion estimation can be performed using an Extended Kalman filter (EKF), e.g. as in [1]. It is also possible to estimate motion separately, using an implicit EKF as in [31]. It is however difficult to analyze stability and convergence properties when an EKF or an IEKF is used. Several attempts have been made to construct on-line structure and motion estimation algorithms using different kinds of observers. Results are obtained for the case of structure estimation assuming known (or estimated) motion, e.g. in [4, 20, 6, 3, 22], however using only one observed point and assuming known or estimated angular and linear velocities, but on the other hand providing different kinds of stability analysis. In [6, 28] a method which allows for stability analysis as well as extension to several points where also angular velocity can be estimated, is presented. The influence of several points when using an Extended Kalman filter is investigated in [28]. An observer for estimation of structure as well as motion is also provided in [4]. Another recent approach, combining an extended Kalman filter with a novel parameterization can be found in [13].

Another study of dynamic models combined with perspective transformations from a control theoretic point of view has been made in [10]. In this study, theoretical aspects, such as controllability and observability, of dynamic systems with a non-linear measurement function similar to a perspective transformation are investigated. However, apart from the results presented in these papers most algorithms for S&M recovery with moving objects contains no modeling of the dynamics. Another attempt based on methods from system identification in automatic control theory can be found in [36], where promising results are obtained.

Some of the early methods for SLAM were focused on sensors such as wheel encoders and laser range finders, and how to use statistical estimation and filtering techniques to determine egomotion and relative position from such data. Since digital cameras and computational power have improved drastically over the years, increasing interest has been given to camera based methods for SLAM. From pioneering works such as [14] and [8] to more recent methods such as the vSLAM system [23] and the MonoSLAM system [7]. In many practical cases, especially for ground robots in indoor environments, the motion of the robot is constrained to a plane parallel to the floor. By considering methods which explicitly assume planar motion, the vertical positioning error of the attached sensors will automatically be bounded over arbitrarily long motion sequences. This insight has successfully been utilized in several visual navigation systems, see for example [12], [25], [43].

In [43] the same problem as in this application is addressed. However, they use a heuristic method based on minimizing an error function over all free parameters and use no deeper insight into the geometry of the problem. In [25] it is found that the eigen-value and the eigenvectors of the homography between two consecutive images can be used to directly solve for the orientation change and the translation respectively of the robot. However, no method for dealing with the hand-eye-calibration problem is given and neither any method for creating a map is given.

Project Description

Given a camera mounted on a robot that is moving on a planar floor that is facing down towards the floor, the SLAM problem can be simplified significantly. We assume that the camera is intrinsically calibrated, i.e. we know the focal length, principal point, skew and aspect ratio, but not the extrinsic calibration, i.e. the relation between the camera coordinate system and the robot coordinate system, the so called hand-eye calibration. We furthermore assume a standard calibrated pin-hole camera model,

$$x \sim PX = K[\,R \mid T\,]X \ , \tag{1}$$

where x denote image coordinates in homogeneous form, X object coordinates in homogeneous form, $\sim$ denotes equality up to scale, P is a (3×4) camera matrix encoding the intrinsic parameters in K and the extrinsic parameters in R (an orthogonal matrix) and T (a translation vector), describing the orientation of the camera with respect to the object. In our case the translation vector only contains two free parameters, representing the translation in the x- and y-direction, while the translation component in the z-direction is constant. Also the orthogonal matrix R only contains one free parameters, Φ, representing rotations orthogonal to the plane. The other two parameters, Ψ and Θ are fixed and represent the tilt of the camera.

Using two different images of the planar floor, taken at different positions and orientations, we can estimate a planar homography, H, between the two images, i.e.,

$$x_1 \sim Hx_2 \ , \tag{2}$$

where x_1 and x_2 denote homogeneous coordinates of corresponding points in image one and two respectively. It turns out that the homography can be written, [40],

$$H = \lambda R_{\Psi\Theta} R_{\Phi} T R_{\Psi\Theta}^T \ , \tag{3}$$

where λ is an unknown scale parameter, $R_{\Psi\Theta}$ represent the tilt, R_{Φ} the planar rotation and T the planar translation. The homography contains 9 parameters and can be estimated linearly from at least 4 point correspondences (because of the unknown scale factor).

Using the special from of the homography in (3) we can derive the following equation

$$R_{\Psi\Theta}^T H^T H R_{\Psi\Theta} = \lambda^2 T^T T = \lambda^2 \begin{bmatrix} 1 & 0 & -t_x \\ 0 & 1 & -t_y \\ -t_x & -t_y & 1 + t_x^2 + t_y^2 \end{bmatrix} \ , \tag{4}$$

where (t_x, t_y) denote the translation. These equations can be used to find constraint Ψ and Θ, but they are highly non-linear.

In summary, we would like to use a series of images from a moving robot and estimate the motion, i.e. (t_x, t_y) and Φ for each position, and at the same time estimate the hand-eye calibration parameters, Ψ and Θ. Then we would like to rectify and stitch together all images to a global map of the floor and use this map to navigate to robot. In addition, we would also like to incorporate other sensors, such as dead reckoning, gyroscopes and inertial sensors, in order both stabilize the process and increase the accuracy of both the map and the position estimation.

WP1: Hand-Eye Calibration

We will develop methods for estimating the relative orientation between the camera and the robot. In the case of a planar motion and a parallel planar scene, the distance between the scene and the scene can not be recovered from visual input without any additional information, such as a given measure on the scene or a known motion. The relevant parameters are the tilt of the camera, represented by Ψ and Θ. The equations in (4) can be used to derive non-linear constraints on these parameters.

One option is to use iterative estimation techniques, i.e. fixing Ψ and estimating Θ and vice versa. Another option would be to find the non-linear constraints a homography matrix H have to satisfy in order to be of the form (3). This will result in a system of polynomial equations and these can be used to define a manifold where the 9 parameters in H must live. We know that the dimension of the manifold i 5, since there are 5 degrees of freedom. This observation tells us that a minimal solver for H would need two and a half point matches, i.e. 2 point matches and the x-coordinate of a third point match. Using the 5 linear equations obtained from these matches, H can be expressed as

$$H = v_1 H_1 + v_2 H_2 + v_3 H_3 + v_4 H_4 \ , \tag{5}$$

where H_i are easily obtained from the linear constraints via SVD (Singular Value Decomposition) and v_i needs to be determined from the non-linear constraint defining the manifold. This can be done using techniques such as the action matrix method [9] or polynomial eigenvalues [24]. These methods have been applied successfully to other vision problems, e.g. [2]. The main advantage with finding a method to estimate the homography from a minimal number of point correspondences is that it could be used to initiate RANSAC-based methods in order to obtain robust solutions.

WP2: Motion Estimation

We will again use the homographies between pair of views to determine the motion of the robot. Assuming that the hand-eye calibration is known, (3) can be used to directly estimate the motion parameters, t and Φ using matrix factorization techniques. One difficulty is that this has to be done at the same time as the hand-eye calibration parameters are determined or updated and it has to be done robustly and stable. Another difficulty is that estimating motions between pair of images and integrating these to a complete motion sequence will in general result in a drift because of accumulating errors. We will explore filtering techniques, such as particle filter, [11], and use loop closing techniques [27] to stabilize the motion estimation process.

We will also investigate the usage of global optimization methods in order to fine-tune the results obtained from the methods above. These methods are based on minimizing some criterion based on the error characteristics of the sensor and feature extractor over the free parameters. In order to obtain efficient methods we believe that these methods can not be used directly, but have to be adapted to the specific problem. One option is to divide the optimization procedure to first deal with sub-paths and then integrate sub-results into a complete solution. Another option is to use modern techniques from convex optimization in order to guarantee a global solution to the problem.

WP3: Mapping and Navigation

We will build a map of the whole floor, based on the estimated motion and hand-eye calibration parameters. The map can be represented by a large image of the floor, that has to be built up from a large number of smaller patches. The main problem is to stitch these smaller patches together in order to produce a useful map. We will investigate different stitching techniques in order to produce the map.

Once the map is produced we would like to use it in order for the robot to perform different tasks using the visual input as guidance for navigation. There are (at least) two different approaches when navigating the robot; either using the whole image and matching it to the map or using a sparse set of feature points distributed on the map. In the latter case we will investigate how many feature point that is needed in order to be able to determine the position of the robot and to navigate from one position to another. We will also investigate filtering techniques for updating the current position of the robot based on the previous position and the visual input.

WP4: Sensor Fusion

It wouldn't be wise to ignore other sensors on the robot and just rely on the visual sensor when information from other sensors are available. In the case of a gyroscope, we immediately obtain an estimate of the rotational velocity, which directly correspond to the rotation angle between two consecutive images. It seems reasonable to combine these measurements into a common filter. One interesting aspect is to take into account the different characteristics of the different sensors, e.g. accuracy, speed, computation time needed, in order to develop optimal filtering techniques.

In the case of an inertial sensor, we obtain a measure of the acceleration of the robot. This information could be integrated (thus adding errors) and feed into a filter together with the visual information. Another approach would be to take the derivatives of the camera equation (1) or the homography (2) in order to obtain equations involving accelerations directly.

The time-plan for the project will be as follows:
Year 1 Develop and analyze algorithms for hand-eye calibration
Year 2 Develop and analyze algorithms for hand-eye calibration and motion estimation
Year 3 Develop and analyze algorithms for mapping and navigation
Year 4 Develop and analyze algorithms for sensor fusion
Year 5 Develop demonstrator

The main responsible for the project will be Prof. Anders Heyden, who has a vast experience in computer vision and digital image analysis. Tekn. Lic. Mårten Wadenbäck will also contribute during his last year as a PhD-student and hopefully also later on. He has already a lot of experience of visual SLAM. We will also recruit a new PhD-student that will be working on several aspects of the proposal, with Prof. Heyden as main supervisor. The project team will work within the mathematical imaging group at the Centre for Mathematical Sciences at Lund University, consisting of 4 professors, 3 senior researchers, 1 research assistant and about 10 PhD-students.

Significance

Research within SLAM has been very popular during the last years, both in the field of computer vision and within the field of automatic control theory, with a large amount of research projects and publications. However, the special case of planar motion and a planar scene has more or less been neglected. One of the few exceptions is [43]. However, they do not exploit the specific geometrical situation and the constraints that could be derived from it, but merely use a brut-force method based on optimizing an error criterion over all free parameters. We strongly believe that we have the background needed to produce break-through research in this area, having experience (on our own or within the mathematical imaging group) with the techniques that need to be used.

It is also evident that from an applied point of view it would be very useful to have stable and robust navigation methods for robots in this specific situation, which is very common in practice. Applications are plentiful, ranging from household robots to industrial robots.

Preliminary Results

We have obtained preliminary results for the hand-eye calibration problem by iteratively solving (4) for the tilt angels by fixing one of them and solving for the other and vice versa, [40]. The results show that for small tilt angels this procedure converges and we can estimate the hand-eye calibration from one homography, see Fig. 1.

This method is extended in [42] in order to use several homographies to robustly estimate the hand-eye calibration parameters. It is shown that the robustness to noise and error in the feature extraction is improved by considering several homographies.

As a by-product of the results above it turned out the the distance between two camera positions can be expressed in terms of the condition number of the inter-image homography. This observation has been used in [41] in order to directly estimate the motion based on a graph-theoretical approach, see Fig. 2.

Finally, initial investigation of sensor fusion of a visual sensor and a gyroscope using a particle filter has been submitted in [23]. It is found that the best results are obtained when using the image data for the weighting step and the gyroscope data for the update step. It is also shown that the resulting motion estimation based on sensor fusion is superior to using only vision or only gyroscope measurements, see Fig. 3.

National and International Cooperation

The Mathematical Imaging Group at Lund University has close contacts with a number of research groups all around the world, within the area of computer vision and digital image analysis. We have different kinds of cooperations with all major computer vision and image analysis groups in Sweden. We also have close cooperation with the department of automatic control at Lund University since more than 20 years and this will serve as a baseline for the experimental part of the project as well as for ideas related to filtering techniques etc.

On an international level we have close cooperations (joint publications or projects) with the following research groups: Copenhagen University, Denmark Technical University, INRIA Rhône-Alpes (MOVI), University of Oxford, Heidelberg University, ETH, Univ. of Western

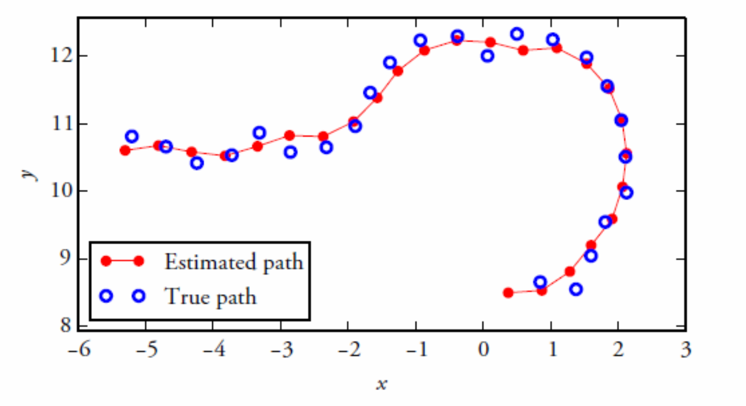

Figure 1: The simulated (blue circles) and estimated path (red bullets) based on iteratively solving for the hand-eye calibration parameters.

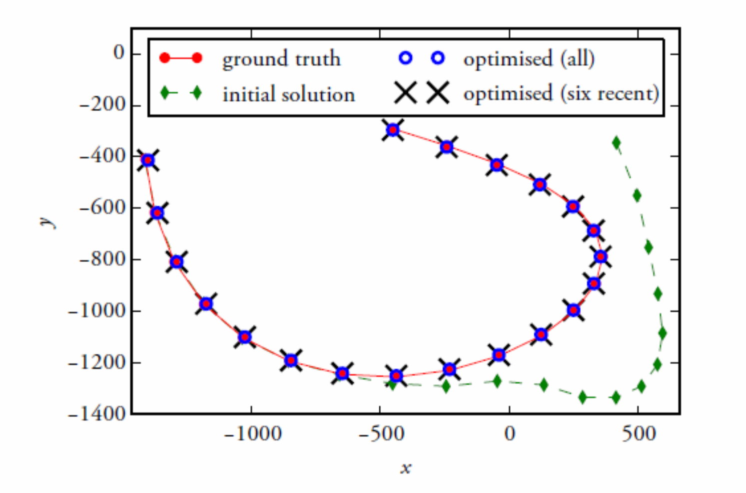

Figure 2: Estimated motion based on condition numbers. Ground truth (red bullets). Initial guess (green diamonds). Optimized solution (black crosses and blue circles).

Australia, National University of Australia, etc.

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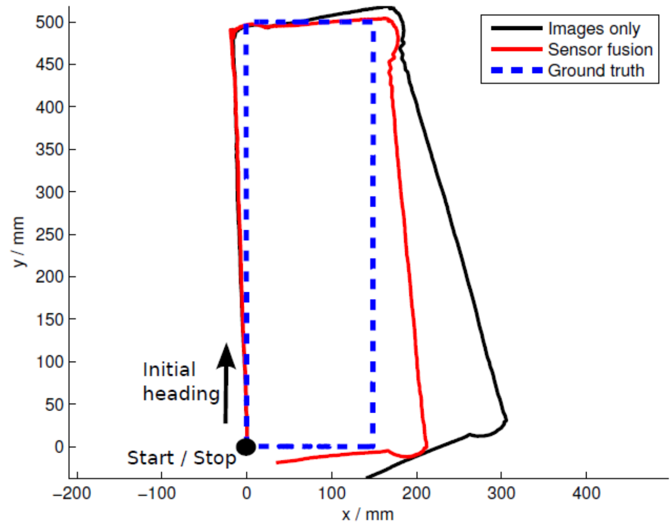

Figure 3: True and estimated positions for visual odometry only (black) and a particle filter for sensor fusion of images and gyroscope measurements (red).

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[26] Y. Ma, S. Soatto, J. Košecká, and S. S. Sastry. *An Invitation to 3-D Vision*. Springer-Verlag, 2004.

[27] P. Newman and K. Ho. Slam-loop closing with visually salient features. In *ICRA 2005: International Conference on Robotics and Automation*, pages 635–642. IEEE, 2005.

[28] F. Nyberg, O. Dahl, J. Holst, and A. Heyden. Using a connected filter for structure estimation in perspective systems. In *Proc. 1st International Workshop on Dynamic Vision*, volume 4358 of *Lecture Notes in Computer Science*. Springer, 2005.

[29] M. Pollefeys, R. Koch, and L. V. Gool. Self-calibration and metric reconstruction in spite of varying and unknown internal camera parameters. In *Proc. Int. Conf. on Computer Vision*, 1998.

[30] S. Soatto and R. Brockett. Optimal structure from motion: Local ambiguities and global estimates. In *Proc. Conf. Computer Vision and Pattern Recognition*, 1998.

[31] S. Soatto, R. Frezza, and P. Perona. Motion estimation via dynamic vision. *IEEE Transactions on Automatic Control*, 41(3), March 1996.

[32] S. Soatto and P. Perona. Reducing structure-from-motion: A general framework for dynamic vision part 1: Modeling. *IEEE Trans. Pattern Analysis and Machine Intelligence*, 20(9):933–942, 1998.

[33] S. Soatto and P. Perona. Reducing structure-from-motion: A general framework for dynamic vision part 2: Implementation and experimental assessment. *IEEE Trans. Pattern Analysis and Machine Intelligence*, 20(9):943–960, 1998.

[34] P. Sturm. Critical motion sequences for monocular self-calibration and uncalibrated Euclidean reconstruction. In *Proc. International Conference on Computer Vision and Pattern Recognition*, 1997.

[35] R. Szeliski. *Computer Vision: Algorithms and Applications*. Springer Verlag, 2010.

[36] M. Sznaier, M. Ayazoglu, and O. I. Camps. Using dynamics to recover euclidean 3-dimensional structure from 2-dimensional perspective projections. In *Control Decision Conference*, pages 2414–2419, 2009.

[37] P. Torr and A. Zisserman. Robust computation and parametrization of multiple view relations. In *Proc. Int. Conf. on Computer Vision*, pages 727–732, Mumbai, India, 1998.

[38] B. Triggs. Differential matching constraints. In *Proc. of the International Conference on Computer Vision and Pattern Recognition*, volume 1, pages 370–376, 1999.

[39] B. Triggs, P. McLauchlan, H. R., and A. Fitzgibbon. Bundle adjustment - a modern synthesis. In *Vision Algorithms'99*, in conjunction with ICCV'99, Kerkyra, Greece, 1999.

[40] M. Wadenbäck and A. Heyden. Planar motion and hand-eye calibration using inter-image homographies from a planar scene. In *Proceedings VISIGRAPP*, pages 164–168, 2013.

[41] M. Wadenbäck and A. Heyden. Trejectory estimation using relaive distances extracted from inter-image homographies. In *CRV'14: Proceedings of the 11th Canadian Conference on Computer and Robot Vision*, pages 232–237, 2013.

[42] M. Wadenbäck and A. Heyden. Ego-motion recovery and robust tilt estimation for planar motion using several homographies. In *Proceedings VISIGRAPP*, pages 635–639, 2014.

[43] J. Zienkiewicz, R. Lukierski, and A. Davison. Dense, automatic calibrating visual odometry from downward-looking camera. In *Proceedings of the British Machine Vision Conference (BMVC)*, 2013.

Interdisciplinarity

My application is interdisciplinary

☐

An interdisciplinary research project is defined in this call for proposals as a project that can not be completed without knowledge, methods, terminology, data and researchers from more than one of the Swedish Research Councils subject areas; Medicine and health, Natural and engineering sciences, Humanities and social sciences and Educational sciences. If your research project is interdisciplinary according to this definition, you indicate and explain this here.

Click here for more information

Scientific report

Scientific report/Account for scientific activities of previous project

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Budget and research resources

Project staff

Describe the staff that will be working in the project and the salary that is applied for in the project budget. Enter the full amount, not in thousands SEK.

Participating researchers that accept an invitation to participate in the application will be displayed automatically under Dedicated time for this project. Note that it will take a few minutes before the information is updated, and that it might be necessary for the project leader to close and reopen the form.

Dedicated time for this project

	Role in the project	Name	Percent of full time
1	Applicant	Anders Heyden	20
2	Participating researcher	Ny Doktorand	80

Salaries including social fees

	Role in the project	Name	Percent of salary	2016	2017	2018	2019	Total
1	Applicant	Anders Heyden	20	362,000	373,000	384,000	395,000	1,514,000
2	Participating researcher	Ny Doktorand	80	543,000	559,000	576,000	593,000	2,271,000
	Total			905,000	932,000	960,000	988,000	3,785,000

Other costs

Describe the other project costs for which you apply from the Swedish Research Council. Enter the full amount, not in thousands SEK.

Premises

Type of premises	2016	2017	2018	2019

Running Costs

	Running Cost	Description	2016	2017	2018	2019	Total
1	Travel	Conferences and visits	100,000	100,000	100,000	50,000	350,000
2	Equipment	Computers	20,000	10,000	20,000	10,000	60,000
	Total		120,000	110,000	120,000	60,000	410,000

Depreciation costs

Depreciation cost	Description	2016	2017	2018	2019

Total project cost

Below you can see a summary of the costs in your budget, which are the costs that you apply for from the Swedish Research Council. Indirect costs are entered separately into the table.

Under Other costs you can enter which costs, aside from the ones you apply for from the Swedish Research Council, that the project includes. Add the full amounts, not in thousands of SEK.

The subtotal plus indirect costs are the total per year that you apply for.

Total budget

Specified costs	2016	2017	2018	2019	Total, applied	Other costs	Total cost
Salaries including social fees	905,000	932,000	960,000	988,000	3,785,000		3,785,000
Running costs	120,000	110,000	120,000	60,000	410,000		410,000
Depreciation costs					0		0
Premises					0		0
Subtotal	1,025,000	1,042,000	1,080,000	1,048,000	4,195,000	0	4,195,000
Indirect costs					0		0
Total project cost	1,025,000	1,042,000	1,080,000	1,048,000	4,195,000	0	4,195,000

Explanation of the proposed budget

Briefly justify each proposed cost in the stated budget.

Explanation of the proposed budget*

The main responsible for the project will be Professor Anders Heyden, who has a vast experience in computer and robot vision.
We will also recruit a new PhD-student that will work exclusively within the project.
We also apply for travel cost to international conferences and visits and for computer costs for the simulations.

Other funding

Describe your other project funding for the project period (applied for or granted) aside from that which you apply for from the Swedish Research Council. Write the whole sum, not thousands of SEK.

Other funding for this project

	Funder	Applicant/project leader	Type of grant	Reg no or equiv.	2016	2017	2018	2019	Total
1	Lund University	Anders Heyden	Faculty means		362,000	373,000	384,000	395,000	1,514,000
2	Lund University	Mårten Wadenbäck	Faculty means		400,000				400,000
	Total				762,000	373,000	384,000	395,000	1,914,000

CV and publications

CV

B: Curriculum Vitae for Anders Heyden

0. Personal Data:
Born: 1965-05-05, Malmö, Sweden, **Married:** to Susanne Heyden, four children
Address: Skogslyckev. 9, SE-24751 Dalby, Sweden, **Citizenship:** Swedish.
Tel: +46 46 2228531, home: +46 46 200584, fax: +46 46 2224010, **email:** heyden@maths.lth.se

1. Master of Science: in Engineering Physics, LTH, Lund University, 1989.

2. PhD: in Mathematics (Mathematics/Applied Mathematics), Lund University, 1995. Title: *Geometry and Algebra of Multiple Projective Transformations*, supervisor: Prof. Gunnar Sparr.

3. Post-doc visits: None

4. Reader: in Mathematics, Lund University, 1999.

5. Currently held Position:
Professor: Centre for Mathematical Sciences, Lund University, Lund, Sweden, (research 25%) 2002-
Managing director: for the program in Engineering Mathematics, Lund University, (30%) 2009-
Director: for research education at Centre for Mathematical Sciences, Lund University, (20%) 2014-

6. Previously held Positions:
Professor: Centre of Technological Studies, Malmö University, Malmö, Sweden, 2002-2009.
Associate Professor: Centre for Mathematical Sciences, Lund University, Lund, Sweden, 1999-2001.
Research Director: WeSpot AB, Ideon, Lund, Sweden, on a part-time basis, 20%, 2000-2002.
Senior Researcher: CellaVision AB, Lund Sweden, on a part-time basis, 20%, 1998-2001.
Research Assistant: Department of Mathematics, Lund University, Lund, Sweden, 1996-1999.
PhD student: Department of Mathematics, Lund University, Lund, Sweden, 1989-1995.

7. In-active periods:
Paternal leave: In total 7 months 1992-2005.
Employment in industry: In total 15 months 1998-2002.

8. Supervision Record:
Doctoral students:
Fredrik Kahl, 2001 (Best nordic thesis within computer vision/image analysis, 2001-2002)
Henrik Malm, 2003
Jan Erik Solem, 2006 (Best nordic thesis within computer vision/image analysis, 2005-2006)
Erik Alpkvist, 2006
Björn Nilsson, 2007 (main supervisor until licentiate thesis, then assistant supervisor)
Ketut Fundana, 2010
Mattias Hansson, 2012 (main supervisor until licentiate level)
Alma Masic, 2013 (main supervisor until licentiate level)
Sebastian Haner, 2014
Licentiate students:
Björn Nilsson, 2003, Nicolas Guilbert, 2004, Adam Karlsson, Pär Hammarstedt, 2005, Fredrik Nyberg 2006, Hanna Källén, 2013, Matilda Landgren, 2014, Mårten Wadenbäck, 2014

9. Other merits of relevance:
Published Books and edited volumes: 6
Contributions to books and book chapters: 4
Publications in International Journals: 45
Publications in Reviewed International conferences: more than 100
Patents: 5 accepted, 2 published and 5 applications (12 in total)

Leader of research projects (current):
On-line Structure and Motion Estimation (SRC) 2012-2014 (2 100 kkr)
Increasing the quality of laboratory tests using image analysis (PEAB) 2014-2016 (1 450 kkr)
ENGROSS (co-leader) (SSF) 2009-2014 (ca 3 000 kkr)

Awards:
Honorable mention for contribution to Intern. Conf. on Comp. Vision, 1995.
Junior Individual Grant from SSF, 2000.
Invited Speaker at Asian Conf. Comp. Vision 2000.
Second price in Innovation Cup Region South (Precise Biometrics), 1999.
Second price in Venture Cup Öresund, (Ludesi), 2001.
Medicon Valley entrepeneurship award (Ludesi), 2001.
Best paper award at Int. Conf. on Automation Robotics and Vision, 2002.
Best poster presentation award at Int. Conf. Computer Vision and Pattern Recognition, 2003.
Nominated for best paper prize at Int. Workshop in Dynamic Vision, 2007.
Invited speaker at SCIA 2013.

Teaching activities:
Teaching assistant in Mathematics, Automatic Control and Computer Science, 1985-1989.
Lecturing in Mathematics, 1996-.

Leadership merits:
Leadership course: During military duty, 1986.
Course in project management: Wenell, 2000.
Project leader: of several research projects, 1997-
Pedagogic course for supervisors of PhD-students, 1999 (Lund Univ.) and 2003 (Malmö Univ.)
Course in research leadership: Fenix, 2004-2005
Leadership education for prospective leaders: Malmo University, 2005.
Course in Pedagogical Leadership: Lund University, 2011.

Other merits of relevance:
Chairman and member of the board of the Swedish Society for Automated Image Analysis, 2011-2014.
Member of the IAPR (International Association of Pattern Recognition) Governing Board. 2011- .
Member of the Swedish National Committee for Mathematics (Royal Swedish Academy of Science), 2011-2014.
Member of the Editorial board for International Journal of Computer Vision and Pattern Recognition Letters.
Member of the Conference Board for European Conf. on Comp. Vision.
Member of the ECMI Educational Committee.
Member of the Management group for the Centre for Mathematical Sciences, Lund University.
Main organizer and program chair for the European Conf. on Comp. Vision, 2002.
Main organizer and general chair for the Scandinavian Conf. on Image Analysis, 2011.
Program Chair for ICPR 2014 and EMMCVPR 2013.
Track Chair for ICPR 2016.
Main organizer for the Int. Workshop on Dynamic Vision, 2005, 2006, 2007 and 2009.
Conference Chair for SSBA Symposium, 2005 and 2015.
Member of the strategic research group at Malmö University, 2003-2006.
Reviewer of research proposals for EU, SRC, SSF, ISF (Israel), EPFL (Switzerland), NWO (The Netherlands), UGC (HongKong), WWTF (Austria) and ANR (France).
Member of the evaluation group for Signals and Systems for SRC, 2013-2014.
Evaluator or research projects for EU.
Co-founder of Ludesi AB.
Co-founder and chairman of the board of Mometric AB.
Tutorials on Multiple view geometry given at all major computer vision conferences 1999-2001.
Opponent for 3 doctoral theses and for 2 licentiate theses.
Delegate in the committee for 18 doctoral theses.

Publication list

C: List of Publications for Anders Heyden, 2008-2015

Google Scholar has been used for citations.

1. Peer-reviewed Journal Articles

[1] Nilsson, B., Johansson, M., Heyden, A., Nelander, S., Fioretos, T., An improved method for detecting and delineating genomic regions with altered gene expression in cancer, *Genome Biology,* Vol. 9, No. 13, 2008. Number of citations: 13

[2] Fundana, K., Overgaard, N.-C., Heyden, A., Variational Segmentation of Image Sequences using Region-Based Active Contours and Deformable Shape Priors, *International Journal of Computer Vision,* Vol. 80, No. 3, pp. 289-299, 2008. Number of citations: 9

[3] Bernstone, C., Heyden, A., Image Analysis for monitoring crack growth in hydropower concrete structures *Journal of the International Measurement Confederation,* 2009. Number of citations: 7

[4] * Dahl, O., Wang, Y., Lynch, A., Heyden, A., Observer Forms for Perspective Systems, *Automatica,* Vol. 46, Iss. 11, 2010. Number of citations: 9

[5] Kirik, U, Cifani, P., Albrekt, A.S., Lindstedt, M., Heyden, A., Levander, F., Multimodel Pathway Enrichment Methods for Functional Evaluation of Expression Regulation, *Journal of Proteome Research,* Vol. 11, No. 5, pp. 2955-2967, 2012. Number of citations: 1

2. Peer-reviewed Conference Contributions

[6] Fundana, K., Gustavsson, D., Overgaard, N.-C., Nielsen, M., Heyden, A., Nonrigid Object Segmentation and Occlusion Detection in Image Sequences, *Proc. International Conference on Computer Vision Theory and Applications*, 2008. Number of citations: ?

[7] Masic, A., Overgaard, N.-C.., Heyden, A., Parameter estimation in biofilm models *Proc. International Conference Biofilm Technologies,* 2008. Number of citations: ?

[8] Dahl, O., Wang, Y., Lynch, A. F., Heyden, A., Observer Forms for Perspective Systems, *Proc. International Federation of Automatic Control (IFAC) World Congress,* 2008. Number of citations: 1

[9] Masic, A., Overgaard, N.-C.., Heyden, A., Investigation of oxygen profile in a nitrifying Moving Bed biofilm process: Theory and validation of a mathematical model. *Proc. IWA World Water Congress,* 2008. Number of citations: ?

[10] Masic, A., Heijman, U., Overgaard, N.-C., Bjerkén, C., Heyden, A., Ståhle, P., A Combined Model for Biofilm Development and Biocorrosion *Proc. SIAM Conference Life Science,* 2008. Number of citations: 1

[11] Gosch, C., Fundana, K., Heyden, A., Schnörr, C., View Point Tracking of Rigid Objects based on Shape Sub-Manifolds, *Proc. European Conference on Computer Vision,* 2008. Number of citations: 5

[12] Huynh, D., Heyden, A., Recursive Structure and Motion Estimation from Noisy Uncalibrated Video Sequences, *Proc. International Conference on Pattern Recognition,* 2008. Number of citations: 1

[13] Nilsson, M., Overgaard, N.-C., Heyden, A., Rayleigh Segmentation of Ultrasound Images of the Human Heart, *Proc. International Conference on Pattern Recognition,* 2008. Number of citations: ?

[14] Dahl, O., Heyden, A., Dynamic Structure and Motion Estimation based on Non-linear Adaptive Observers, *Proc. International Conference on Pattern Recognition,* 2008. Number of citations: 5

[15] Fundana, K., Heyden, A., Ghosch, C., Schnörr, C., Continuous Graph Cut Segmentation with Shape Priors, *Proc. International Conference on Pattern Recognition,* 2008. Number of citations: 9

[16] Overgaard, N.-C., Fundana, K., Heyden, A., Pose invariant shape prior segmentation using continuous graph cuts and gradient descent on Lie groups *Proc. International Conference on Scale Space and Variational Methods,* 2009. Number of citations: 1

[17] Dahl, O., Heyden, A., A Parameter Estimation Based Approach to Structure and Motion Estimation in Perspective Systems, *Proc. European Control Conference,* 2009. Number of citations: ?

[18] Delaunoy, A., Fundana, K., Prados, E., Heyden, A., Convex Multi-region Segmentation an Manifolds, *Proc. International Conference on Computer Vision,* 2009. Number of citations: 14

[19] Heyden, A., Dahl, O., Provably Convergent On-line Structure and Motion Estimation for Perspective Systems, *Proc. International Workshop on Dynamic Vision,* 2009. Number of citations: 3

[20] Koskenkorva, P., Brandt, S., Heyden, A., Uncalibrated Non-rigid Factorization with Automatic Shape Basis Selection, *Proc. International Workshop on Non-rigid Shape Analysis and Deformable Image Alignment,* 2009. Number of citations: 3

[21] Masic, A., Bengtsson, J., Overgaard, N.-C., Christensson, M., Heyden, A., Determination of the oxygen profile in a nitrifying Moving Bed Biofilm Reactor by microelectrodes and a mathematical model *Proc. Processes in Biofilms: Fundamentals to Applications,* 2009. Number of citations: ?

[22] * Heyden, A., Dahl, O., Provably Convergent Structure and Motion Estimation for Perspective Systems, *Proc. Control Decision Conference,* 2009. Number of citations: 1

[23] Heyden, A., Sparr, G., Bridging the Gap Between Mathematics and Industry: Master of Science Education in Engineering Mathematics at Lund University, *EIMI Study Volume, Educational Interfaces Between Mathematics and Industry,* 2010. Number of citations: ?

[24] Haner, S., Heyden, A., A Step Towards Self-Calibration in SLAM: Weakly Calibrated On-line Structure and Motion Estimation, *Proc. International Workshop on Mobile Vision,* 2010. Number of citations: ?

[25] Nyman, P., Åström, K., Heyden, A., Multi-camera Platform Calibration using Multi-linear Constraints, *Proc. International Conference on Pattern Recognition,* 2010. Number of citations: 2

[26] Haner, S., Heyden, A., On-line Structure and Motion Estimation based on an Extended Kalman Filter and a Novel Paramterization, *Proc. International Conference on Pattern Recognition,* 2010. Number of citations: 2

[27] Haner, S., Heyden, A., Optimal View Path Planning for Visual SLAM, *Proc. Scandinavian Conference on Image Analysis,* 2011. Number of citations: 6

[28] Khani, S., Ahmadi, M., Heyden, A., 3D measurement analysis method development for classification of chewing gums, *Proc. Scandinavian Workshop on Imaging Food Quality,* 2011. Number of citations: ?

[29] Källén, H., Heyden, A., Åström, K., Lindh, P., Measurement of Bitumen Coverage of Stones for Road Building, based on Digital Image Analysis, *Proc. International Workshop on Applications of Computer Vision,* 2012. Number of citations: ?

[30] Haner, S., Heyden, A., Covariance Propagation and Next Best View Planning for 3D Reconstruction, *Proc. European Conference on Computer Vision,* 2012. Number of citations: 4

[31] Pinies, P., Paz, L.M., Haner, S., Heyden, A., Decomposable Bundle Adjustment using a Junction Tree, *Proc. International Conference on Robotics and Automation,* 2012. Number of citations: 4

[32] Wadenbäck, M., Heyden, A., Planar Motion and Hand-Eye Calibration using Inter-Image Homographies from a Planar Scene, *Proc. International Conference on Computer Vision Theory and Applications,* 2013. Number of citations: ?

[33] Källén, H., Heyden, A., Lindh, P., Measurement of Bitumen Coverage of Stones using a Turntable and Specular Reflections, *Proc. International Conference on Computer Vision Theory and Applications,* 2013. Number of citations: ?

[34] Landgren, M., Overgaard, N.-C., Heyden, A., Segmentation of the Left Heart Ventricle in Ultrasound Images using a Region-based Snake, *Proc. SPIE Medical Imaging,* 2013. Number of citations: 3

[35] * Wadenbäck, M., Heyden, A., Ego-Motion Recovery and Robust Tilt Estimation for Planar Motion using Several Homographies, *Proc. International Conference on Computer Vision, Imaging and Computer Graphics,* 2014. Number of citations: ?

[36] * Wadenbäck, M., Heyden, A., Trajectory Estimation using Relative Distances Extracted from Inter-Image Homographies, *Proc. International Conference on Computer and Robot Vision,* 2014. Number of citations: ?

[37] Diehl, S., Heyden, A., Perna, S., A One-Dimensional Moving-Boundary Model for Tubulin-Driven Axonal Growth, *Proc. 9th International Conference on Mathematical and Theoretical Biology,* 2014. Number of citations: ?

[38] Landgren, M., Overgaard, N.-C., Heyden, A., A Measure of Septum Shape using Shortest Path Segmentation in Echocardiographic Images of LVAD Patients, *Proc. International Conference on Pattern Recognition*, 2014. Number of citations: ?

[39] * Haner, S., Heyden, A., Discrete and Optimal View Path Planning, *Proc. International Conference on Computer Vision Theory and Applications*, 2015. Number of citations: ?

[40] Haner, S., Svärm, L., Ask, E., Heyden, A., Joint Under and Over Water Calibration of a Swimmer Tracking System, *Proc. International Conference on Pattern Recognition Applications and Methods*, 2015. Number of citations: ?

3. Books, Edited Volumes and Contributions to Books

[41] Heyden, A., *Proceedings Swedish Symposium on Image Analysis 2005*, Malmo University, 2005.

[42] Heyden, A., Pollefeys, M., Multiple View Geometry, *in Emerging Topics in Computer Vision*, Ed. G. Medioni, Prentice Hall, 2003, pp. 47-112.

[43] Heyden, A., Three-dimensional Geometric Vision, *in Handbook of Computer Vision: Applications in Pattern Recognition, Computer Vision, Neuralcomputing, and Robotics* Ed. E. Bayro-Corrochano, Springer Verlag, 2005, pp. 305-348.

[44] Heyden, A., Vidal, R., Ma, Y., (editors) *Dynamical Vision: ICCV 2005 and ECCV 2006 Workshops WDV 2005 and WDV 2006, Revised Papers*, Springer Lecture Notes in Computer Science, Vol. 4358, 2007.

[45] Heyden, A., Vidal, R., Ma, Y., (editors) *Proceedings of the third International Workshop on Dynamical Vision*, in conjunction with ICCV 2007, 2007.

[46] Heyden, A., Vidal, R., Ma, Y., (editors) *Proceedings of the third and fourth International Workshop on Dynamical Vision*, in conjunction with ICCV 2009, 2009.

[47] Mörken, K, Weichert, J., Heyden, A., (editors) *Special Issue for International Conference on Scale Space and Variational Methods*, International Journal of Computer Vision, 2009.

[48] Heyden, A., Kahl, F., (editors) *Proceedings Scandinavian Conferene on Image Analysis 2011*, Springer Lecture Notes in Computer Science, Vol. 6688, 2011.

[49] Heyden, A., Felsberg, M., Borga, M., Laruendeau, D, (editors) *Proceedings International Conference on Pattern Recognition 2014*, IEEE, 2014.

[50] Heyden, A., Wadenbäck, M., *Proceedings Swedish Symposium on Image Analysis 2015*, Lund University, 2015.

4. Survey Papers

None

5. Patents

[51] Lantz, M., Lundgren, L.-G., Larsson, N., Heyden, A., Microscope and method for compressing and storing of digital images, *PCT publication number WO0127678, Swedish Patent number SE514009C2*, 2000.

[52] Pettersson, M., Rosenqvist, A., Heyden, A., Almers, M., Feature-free registration of dissimilar images using a robust similarity metric, *PCT publication number WO9931622A1*, 2000.

[53] Heyden, A., Microscope filter for automatic contrast enhancement, *PCT publication number WO104683A1*, 2000.

[54] Heyden, A., Method, device and computer program for monitoring an area, *PCT publication number WO0148696*, 2001.

[55] Heyden, A., , Håkansson, J., Wallin, B.,Karlsson, A., Microscope and method for manufacturing a composite image with a high resolution, *PCT publication number WO0127679*, 2001.

[56] Rosenqvist, A., Almers, M., Heyden, A., Focus deviation estimation method in optical system, involves modifying sharpness of image by processing predetermined degree so that two images are equally sharpened, *PCT publication number WO0239059, SE0004046*, 2002.

[57] Heyden, A., Multiple backgrounds, *US2002039135*, 2002.

[58] Heyden, A., Invariant filters (Adjusted filters), *PCT publication number WO03001810, US2003053660*, 2003.

[59] Esping, S., Heyden, A., Door opening device, includes monitoring unit with light sensitive sensor located close to door rotation axis, *SE0103226*, 2003.
[60] Heyden, A., Sjö, E., Benckert, H., Sensor arrangement and method for calibrating the same area, *PCT publication number WO03091961*, 2003.
[61] Heyden, A., Malmström, L., Malmström, J., Forsström-Olsson, O., Berglund, M. P., Method and computer program for digital image processing for two-dimensional electrophoresis, *US2005063574, PCT publication number WO2003SE00029*, 2003.
[62] Wallmark, G., Heyden, A., Karlsson, A., Forsström-Olsson, O., Method and means for 2D-gel-image segmentation, *PCT publication number WO2004001671*, 2003.

6. Computer Programs

None

7. Popular Science Publications and Presentation

[63] Presentation of Mathematical Modeling at Malmo University on several occasions, 2002-2008.
[64] Presentation of Image Analysis and Computer Vision at "Matematikbiennalen" in Malmo, 2003.
[65] Presentation of Applied Mathematics at "Rotary" in Malmo, 2005.

8. Other Conferences

[66] Dahl, O., Heyden, A., Exact Observer Error Linearization for Perspective Dynamic Systems, *Proc. Swedish Symposium on Image Analysis*, 2008.
[67] Hansson, M., Overgaard, N.-C., Heyden, A., Coupled Active Contours with Application to Rayleigh Segmentation of Echocardiographic Images, *Proc. Swedish Symposium on Image Analysis*, 2008.
[68] Dahl, O., Heyden, A., A Parameter Estimation Based Approach to S&M Estimation, *Proc. Swedish Symposium on Image Analysis*, 2009.
[69] Nyman, P., Åström, K., Heyden, A., Multi-camera Platform Calibration using Multi-linear Constraints, *Proc. Swedish Symposium on Image Analysis*, 2010.
[70] Haner, S., Heyden, A., On-line Structure and Motion Estimation based on an Extended Kalman Filter and a Novel Paramterization, *Proc. Swedish Symposium on Image Analysis*, 2010.
[71] Dahl, O., Wang, Y., Lynch, A. F., Heyden, A., Observer Forms for Perspective Systems *Proc. Reglermöte*, 2010.
[72] Haner, S., Heyden, A., Optimal View Path Planning for Visual SLAM, *Proc. Swedish Symposium on Image Analysis*, 2011.
[73] Haner, S., Heyden, A., Covariance Propagation and Next Best View Planning for 3D Reconstruction, *Proc. Swedish Symposium on Image Analysis*, 2012.
[74] Källén, H., Heyden, A., Åström, K., Lindh, P., Measurement of Bitumen Coverage of Stones for Road Building, based on Digital Image Analysis, *Proc. Swedish Symposium on Image Analysis*, 2012.
[75] Landgren, M., Overgaard, N.-C., Heyden, A., A Region-based Snake Segmentation of the Left Heart Ventricle in Ultrasound Images, *Proc. Swedish Symposium on Image Analysis*, 2013.
[76] Wadenbäck, M., Heyden, A., Planar Motion and Hand-Eye Calibration using Inter-Image Homographies from a Planar Scene, *Proc. Swedish Symposium on Image Analysis*, 2013.
[77] Heyden, A., Overgaard, N.-C., Matematik på Teknisk Matematik: Inrättande av Karaktärskurser, *Proc. 4:e Utvecklingskonferensen för Sveriges Ingenjörsutbildningar*, 2013.
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Most cited publications

[1] Heyden, A., Åström, K., Euclidean Reconstruction from Image Sequences with Varying and Unknown Focal Length and Principal Point, *Proc. CVPR'97, IEEE Computer Society Press,* 1997, pp. 483-443. Number of citations: 260

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[5] Heyden, A., Reconstruction from Image Sequences by means of Relative Depths, *International Journal of Computer Vision, Vol. 24, No. 2,* 1997, pp. 155-161. Number of citations: 92

CV

Name: Anders Heyden	**Doctorial degree:** 1995-12-15
Birthdate: 19650505	**Academic title:** Professor
Gender: Male	**Employer:** Lunds universitet

Research education

Dissertation title (swe)

Geometri och algebra för multipla projektiva transformationer

Dissertation title (en)

Geometry and Algebra of Multiple Projective Transformations

Organisation	Unit	Supervisor
Lunds universitet, Sweden Sweden - Higher education Institutes	Matematikcentrum 107150	Gunnar Sparr
Subject doctors degree	**ISSN/ISBN-number**	**Date doctoral exam**
10199. Annan matematik	91-628-1784-1	1995-12-15

Publications

Name: Anders Heyden	**Doctorial degree:** 1995-12-15
Birthdate: 19650505	**Academic title:** Professor
Gender: Male	**Employer:** Lunds universitet

Heyden, Anders has not added any publications to the application.

Register

Terms and conditions

The application must be signed by the applicant as well as the authorised representative of the administrating organisation. The representative is normally the department head of the institution where the research is to be conducted, but may in some instances be e.g. the vice-chancellor. This is specified in the call for proposals.

The signature*from the applicant*confirms that:

- the information in the application is correct and according to the instructions form the Swedish Research Council
- any additional professional activities or commercial ties have been reported to the administrating organisation, and that no conflicts have arisen that would conflict with good research practice
- that the necessary permits and approvals are in place at the start of the project e.g. regarding ethical review.

The signature *from the administrating organisation* confirms that:

- the research, employment and equipment indicated will be accommodated in the institution during the time, and to the extent, described in the application
- the institution approves the cost-estimate in the application
- the research is conducted according to Swedish legislation.

The above-mentioned points must have been discussed between the parties before the representative of the administrating organisation approves and signs the application.

Project out lines are not signed by the administrating organisation. The administrating organisation only sign the application if the project outline is accepted for step two.

Applications with an organisation as applicant is automatically signed when the application is registered.