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Research Article

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POSITION ESTIMATION OF ROBOTIC PLATFORM USING OPTICAL FLOW

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ABSTRACT

This paper deals with a base research of an alternative type of navigation for our project ARES (Autonomous Research Exploration System). This system is focused on exploration of unknown areas. The navigation of this platform is based on fusion of several navigation methods. The first method is based on the visual odometry using SURF (Speeded Up Robust Feature). The second navigation method is based on Hector Slam and Lidar sensor. The third method is based on optical flow. The implementation of third method based on the Lucas-Kanade method is descripted in this paper.

Keywords: Robot navigation, Visual Odometry, Lucas-Kanade, Optical Flow

INTRODUCTION

This paper starts to research an alternative type of navigation forour project ARES. Project ARES is focused on preparing a 3D space map and navigation of a robotics platform in unknown areas. In exterior spaces, researchers can use a satellite navigation system which has high precision of position estimation, typically better than 3 meters. Unfortunately, in our research we are focused on unknown interior spaces and in this case, satellite navigation is unsuitable due to a lot of signal dropouts.

An alternative navigation system based on Speeded-Up Robust Feature is developed and descripted in (Beran et al, 2015a), (Murillo et al, 2007). This method is suitable only for spaces with a structured background where an algorithm can calculate many interesting points.

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When comparing two sequenced frames,an algorithm calculates pixel distances between interesting points calculated in each frame. Pixel distances are recalculated using the mathematical model descripted in (Beran et al, 2015b).

An alternative navigation system based on image processing methods is a method called SLAM. In our second research, we are developing a navigation method based on LIDAR and Hector SLAM. This method provides a precision navigation system using LIDAR, Robotics Operation System (ROS) installed on Raspberry Pi, and Hector SLAM. The big advantage is independence on other navigation methods. This method will be described in (Vanicek et al, 2017, unpub).

The navigation method using optical flow is also available. The optical flow is typically used for object detection and tracking. This problematic is descripted in (Patel and Parmar 2014). The optical flow used for robot navigation is descripted in (Zingg et al, 2010) or (Chao et al, 2013). Also, optical flow is commonly used for object detection, for example at railway crossing or moving objects in image. Implementation of the optical flow for obstacle detection on the Railway crossing is described in (Silar and Dobrovolny,2013a) or (Silar and Dobrovolny,2013b)

Nowadays, our project contains several different types of position estimation. Every type of position estimation works on a different principle. The first method of position estimation is based on Inertial Measurement Unit (IMU) and implementation of Direct Cosine Matrix (DCM). This method is descripted in detail in(Beran et al, 2014). The second part is based ona visual odometry method based on the Speeded-Up Robust Feature (SURF) method. More information about this research is written in (Beran et al, 2015a), and (Beran et al, 2015b). The third main part is based on a 3D space scanner. For an accurate 3D space map, this system needs precision of position estimation, better than ±30 cm. Only in this case our system is able to be synchronized. The 3D space mapping system is described in detail in (Chmelar et al, 2014). The latest results of development were published in the paper (Chmelar et al, 2017). If our system, based on 3D space scanner is synchronized, we can use this system for another type of high precision position estimation source.

The accurate position estimation is provided using sensor fusion. In our case, we plan to use visual odometry(using SURF), navigation (using Hector SLAM), mechanical odometry, and inertial navigation. These data streams will be filtered using a Kalman filter, which will provide accurate position estimation. The methods of sensor fusion are described in detail in (Beran et al, 2014) and (Beran et al, 2016). The alternative usable data stream will be based on optical flow. Development of this alternative position estimation system based on the Lucas-Kanade method is described in this paper.

OPTICAL FLOW

The optical flow method, describes the direction and time rate of pixels in a sequence of two images. The result of this method is a 2D matrix, which carries information of direction and velocity of motion. This value is assigned to each pixel. For simplified and accelerated calculations, the real-world objects (three dimension and time) can be transferred to two-dimensional objects moving in time t. The object in the image is represented by a two-dimensional brightness function of location and time. This function can be mathematically written as I(x,y,t). Where x and y are pixel positions and t is time. The object moving in sequenced frames can be expressed as (1).

$$I(x,y,t) = I(x+\Delta x, y+\Delta \mathrm{y}, \mathrm{t}+\Delta \mathrm{t}) \quad (1)$$

Using the Taylor polynomic series for the right part of equation, (1) we get equation (2).

$$I(x,y,t) = I(x,y,t) + \frac{\partial I}{\partial x}\delta x + \frac{\partial I}{\partial y}\delta y + \frac{\partial I}{\partial t}\delta t + +Higher\ derivate\ terms \quad (2)$$

When neglecting the higher Taylor polynomic series term, and other modifications we get a simpler equation (3)

$$\nabla I \cdot \vec{v} = -I_d \quad (3)$$

Where∇I is intensity brightness gradient, $\vec{v}$ is velocity vector (optical flow) of image pixels, $\mathrm{I_d}$ is the time derivation of brightness intensity. Equation (3) is very important for flow calculations and this equation is called the 2D motion Constraint Equation (Barron and Thacker 2005),(Barron, 2009).

Lucas-Kanade method

The Lucas-Kanade method is a widely used method developed for optical flow estimation, and developed by B.D.Lucas and T. Kanade. More information about this method is written in (Lucas and Kanade, 1983)

$\rho_{LK} = \sum_{x,y\in\Omega} W^2(x,y)[\nabla I(x,y,t)\cdot\vec{v} + I_d(x,y,t)]^2$ (4)

Where Ω □is the neighborhood of the pixel; W(x,y) are assigned weights to an individual pixel in Ω

The derivation of error term ρ_{LK} must be computed to find the minimal error of the induvial components of velocity. When minimal error, several adjustments, and transfer matrix are found, optical flow calculation can be calculated using the next equations.

$$\vec{v} = [A^T W^2 A]^{-1} A^T W^2 \vec{b} \quad (5)$$

$$A = [\nabla I(x_1,y_1),\cdots,\nabla I(x_N,y_N)] \quad (6)$$

$$W = diag[\mathrm{W}(x_1,y_1),\cdots,\mathrm{W}(x_N,y_N)] \quad (7)$$

$$\vec{b} = -[\mathrm{I_d}(x_1,y_1),\cdots,\mathrm{I_d}(x_N,y_N)] \quad (8)$$

Where N is number of pixels (N = n x n of Ω neighbourhood) and $x_i,y_i \in \Omega$

The result of equation (4) is the velocity of one pixel. Instead of calculating the sums, the convolution by means of Gaussian or difference temporal gradient filter, is used to reduce algorithm complexity. The equations (6) to (8) are only descripted parameters used in equation (5).

SYSTEM CONFIGURATION

Our project will be used for navigation in unknown spaces such as multisensory fusion. Description of used sensors is written in this chapter. In our research we are using a robotic platform. The parameters of this platform are written in Table 3.

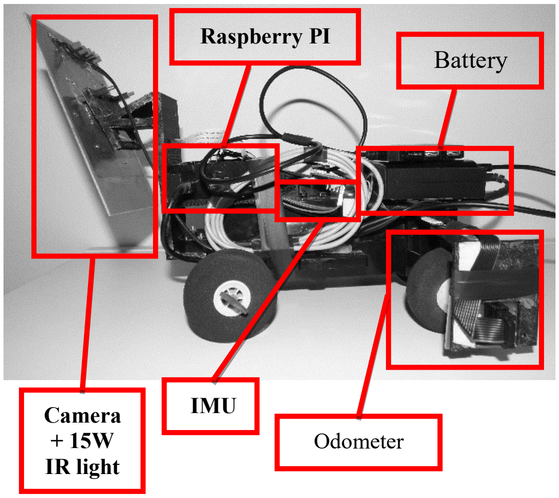

Fig.1. Robotics platform

Raspberry PI

The Raspberry PI microcomputer is used because this system is cheap, commonly used and supported from ROS. Also, on this system, a lot of tutorials exist on how to use this system with several types of sensors. In our system, a Unix based operation system called Ubuntu Mate was used. In our system Robotics Operation System (ROS) was installed for sensor support. This ROS provides client server communication with ROS nodes, and data from these nodes can be published directly to Matlab software with the installed ROS toolbox. Also, ROS has a lot of tutorials how to run this system and the system has a numerous problem solving community. These properties provide advantages for fast system development without significant problems. More information about ROS is available in (ROS web, 2017).

Table 1. Raspberry Pi parameters

Type	**Parameters**
Raspberry PI 2	Broadcom BCM2836 ARM Cortex A7, 4 x 900 MHz, 1 GB LPDDR2 SDRAM
IR Camera	OV05647-G04A, Pixel size 1.4×1.4µm, Frame rate: 1080p (30 fps), 960p (45 fps), 720p (60 fps), 640×480 (90 fps), 320×240 (120 fps), lens chiev array (24°), no infrared filter
IR light	15 x 1W LED GT-P04IR4101, 850nm

Odometer

The odometer sensor was developed using a EAW0J B24 AE0128L sensor. This sensor has 128 step position encoding and provides high precision position determination and is directly connected to rear wheels. The ROS has no support for this type of sensor and user-firmware was developed under ROS. The developed firmware will be published for use under ROS. All parameters are written in Table 2.The values from the optical odometer are used for calibration of measured trajectory in one dimension.

Table 2: Odometer parameters

Type	Parameter
Sensor type	Bourns EAW0J-B24-AE0128L Absolute Position Encoder
Resolution	8bit code with 128 steps per rotate
Operating RPM	Max 120 rpm
Mechanical Angle	Continuous 360°
Position estimation error	$\pm\frac{\Delta}{2} \approx 0{,}7mm$

Table 3. Chassis parametre

Parameter	Value
Nr. of Wheels	4
Wheel diameter	58 mm
Wheel circumference	182,21mm
Chassis type	Automobile type

OPTICAL FLOW POSITION ESTIMATION ALGORITHM

The algorithm description is shown in Fig.2. Our platform contains a raspberry Pi with connected camera. Our platform is shown in Fig.1. The camera captures the floor with some objects. These images are sent to the Matlab software using Wi-Fithrougha Robot Operation System (ROS). This ROS providesa set of libraries and communication methods for speed and easy sensor implementation and data measurement. More information about this Robots system is available in (ROS,2017). The captured data are used for optical flow calculations in Matlab using the Lucas-Kanade algorithm. The Region of Interest (ROI) is selected in the middle of the image.

The data filtration is a very important part of estimation of the moving vector. Calculated data includes several extreme values,which depend on background structure. The extreme values are shown in **Fig.**3 . These extreme values rapidly decrease the precision of position estimation and these values must be filtered. In our research, we are using simple Gaussian filtration to remove extreme values.

$$x_i = \begin{cases} x_i, & x_i \in \mu \pm k\sigma \\ [\,], & other \end{cases} \qquad (9)$$

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2} (10)$$

Where xi are measured data, μ is data mean, k is width of Gauss interval (k=1 cover around 68% of all data range, k=2 cover around 95% of all data range); N is amount of data; empty brackets [ ]indicateerased data.

In our case, we are using k = 1.

All movements we can divide into direct moves and curves. The data is evaluated using the algorithm:

1) Extreme values are removed using (9) and (10)
2) Calculate data mean and median
3) If data mean and median is similar, movement is probably direct – the optical flow direction are symmetrical
4) If data mean and data median are different than threshold, movement is probably like a curve. The optical flow direction is oriented to one side.
5) If calculated direction of movement has high difference with respect of previous value, decrease Gauss interval size to eliminate extreme values.

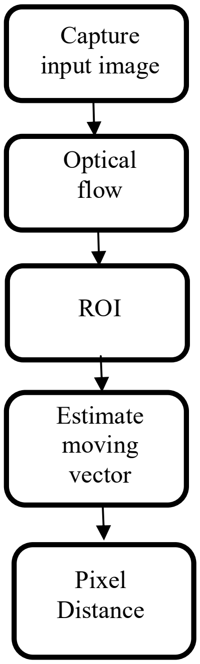

Fig.2. Block diagram

RESULTS

In our research, we measure and record several paths. Nowadays, this recorded data is processed as post processing in Matlab software. For future, this data will be processed online. In our research, the optical flow detection is used for position estimation in pixel distances. For the future, these pixel distances will be transformed to real coordinates using geometrical transformation similar to geometrical transformation descripted in (Beran et al 2015b). In this base research, we made thirty total repetitions of different direct path length. The results of measurements compared with real path length are written in Table 4. The results are shown in pixel distances. In the future, these pixel distances will be transformed to real coordinates.

Table 4. Path length measurement results

Meas. Nr.		Path length		
		1m [pix]	3m [pix]	5m [pix]
X	Mean [pix]	1245,24	3798,41	6249,78
	Std.dev [pix]	18,07	25,42	29,05
Y	Mean [pix]	1,51	2,47	-2,34
	Std.dev [pix]	3,45	4,27	6,23

Also, paths which contain direct move and curve were tested. An example of estimated optical flow at curve is shown in **Fig.**3. An example of estimated direct move is shown in Fig.4. In the figures, ROI is shown using a green square; the center of the image is shown using a green cross. The red arrows indicate direction and magnitude of optical flow. Detected moving vector is shown using green line. For better visibility, the length of moving vector is greater than a real detected magnitude

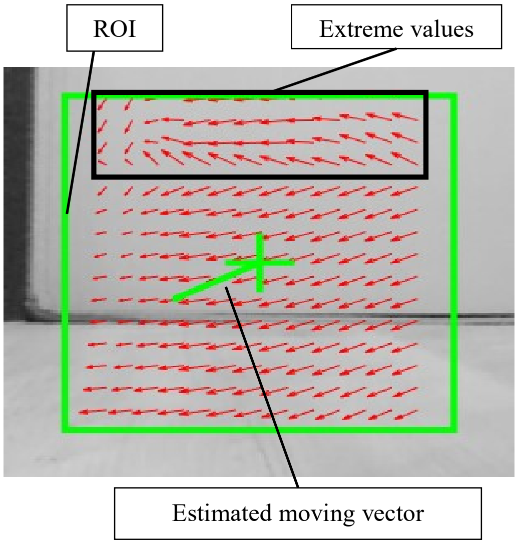

Fig.3. Example of estimated curve

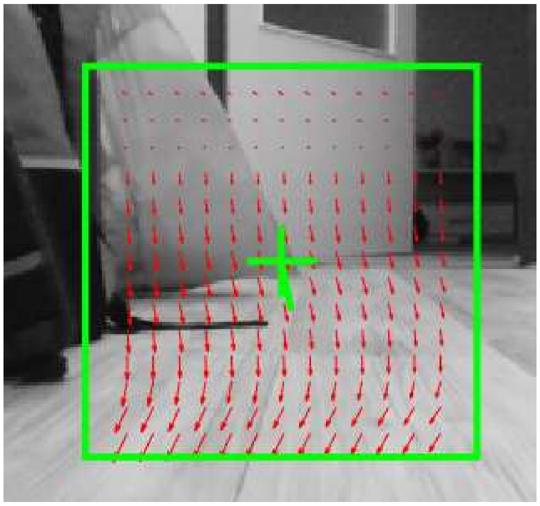

Fig.4. Example of estimated direct move

The first five measurements and estimated 5-meter direct path are shown in Fig.5. These paths are compared with a real path length.

CONCLUSION AND FUTURE WORK

Our project is focused on navigation in unknown spaces. The project is divided to several parts – 3D Space mapping using rotary rangefinder, 2D space mapping using Lidar and Hector SLAM, and Inertial Navigation. This method provides a 2D space map and calculated trajectory. This trajectory will be used as an alternative navigation data source. This project contains methods for visual odometry navigation and we implement visual odometry based on SURF method and Optical Flow.

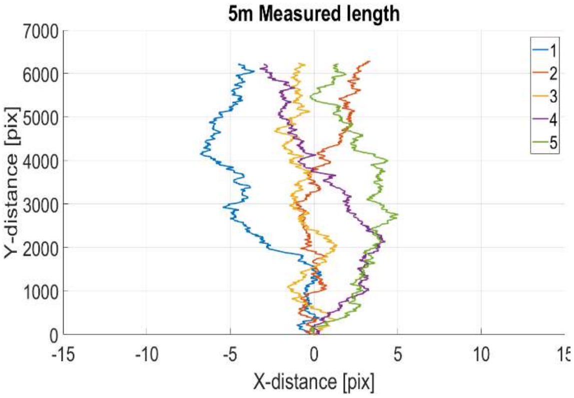

Fig.5. Example of estimated direct 5mpath length using optical flow

In this paper, implementation of Optical Flow (Lucas-Kanade method) was descripted. Also, it is necessary to develop a mathematical model for transformation of pixel distances calculated using optical flow to real distances,for example, in millimetres. The mathematical model is complicated and highly important for accurate. Also, for future use, we must recalculate curve path to true path using Direct Cosine Matrix and gyroscopes.

For the future, we plan to implement multisensory fusion using Inertial Measurement Unit, visual odometry using SURF and optical flow, 2D and 3D space mapping. Fusion of these sensors providesan accurate and reliable space mapping system. Also, for future it is necessary to transform our methods from a post-processing variant to an online variant of the robotics platform navigation and space exploring

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