OPTICAL NAVIGATION SENSOR
Incorporating Vehicle Dynamics Information in Mapmaking

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Abstract: Accurate odometry and navigation may well be the most important tasks of a mobile robot's control system. To solve this task it is necessary to utilize proper sensors which provide reliable information about the motion. This paper presents the prototype of an optical navigation sensor which can be an alternative choice for the dead reckoning navigation system of a vehicle or mobile robot. The last part of the paper presents another application in an inertial navigation system that enables a new approach to map making which incorporates vehicle dynamics into the world map.

1 INTRODUCTION

Autonomous mobile robots gain more and more importance in automotive, domestic and military applications. Sensing and interpreting their surroundings correctly are crucial in all these areas. The sensor presented in this paper aims to improve existing odometry methods, and to aid the creation of world maps that incorporate the state of the vehicle in the world map and classifies terrain accordingly. In the first half of this document an overview of the principle and the prototype of the optical navigation sensor are presented, the second section of the paper proposes a method for world model building for mobile robots and shows some other application where this sensor can be used.

2 NAVIGATION TECHNIQUES

Accurate self localization is one of the most important topics in autonomous vehicle technology. During centuries researchers have developed a lot of techniques to measure the precise position of land or aerial vehicles and mobile robots.

Global methods (e.g. GPS) determine directly the absolute position, but unfortunately in several cases these are not useable, due to reception problems.

Dead reckoning methods estimate the present location of a navigating agent by advancing some previous position using known course, velocity and time information (Borenstein, 1996).

The odometry (the most simplistic and prevalent implementation of dead reckoning) estimates the course and distance of the moving agent's path to calculate the global location by measuring the wheel rotation and/or the steering orientation (Dixon, 1997). This position estimating can be strongly inaccurate under real conditions through the mobility configuration (e.g. tracked vehicles) or through the wheel-slippage, overacceleration or driving over uneven floor.

3 OPTICAL NAVIGATION SENSOR

3.1 Optical Flow

Through of the inaccuracy of the odometry it is necessary to develop a cheap sensor-system that provides well-authenticated dislocation-data for dead reckoning navigation in real world conditions. The optical navigation sensor is a possible solution to fulfil these conditions.

The working principle of the sensor is optical flow, namely the motion information is generated from visual information (from an image-sequence provided by a camera facing the ground). Typically the motion is represented as vectors originating or

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terminating at pixels in a digital image sequence (CVRG, 2000). An example is shown in figure 1.

a.) b.) c.) d.) e.)

Figure 1: The principle of the optical flow.

3.2 The Prototype of the Sensor

As a basis for further research, we have built the prototype of the optical navigation sensor (see figure 2 and figure 3).

As a camera (what provides the image-sequence for calculating the dislocation) we have chosen the sensing and processing chip of a low-cost and wide-spread optical mouse. (Hereinafter this chip is referred to as “mouse-chip”.) The chip includes a low-resolution camera and a DSP for calculating the optical flow by hardware at a very high rate. Although its resolution is relatively low, for motion detection and measurement it is sufficient because only the texture is important. It measures the relative dislocations in the x and y direction.

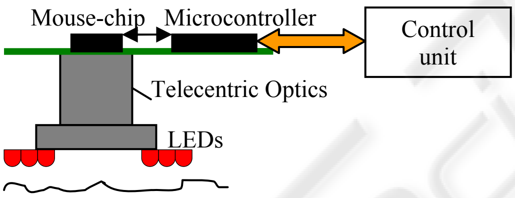
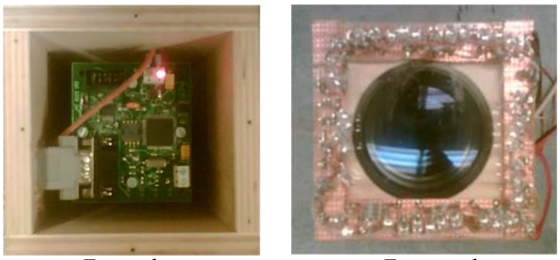


Figure 2: The model of the sensor.

Because of the uneven floor the distance between the sensor and the floor is continuously changing. To compensate this effect the sensor has telecentric optics, which has a constant magnification rate therefore in a certain range the measurements are independent from the height of the sensor relative to the ground.

Naturally, it was necessary to design a microcontroller based architecture round the mouse-chip which offers a useable interface for a dead reckoning navigation system. The microcontroller reads the motion or the image information of the mouse-chip and sends them to the processing unit, for example to a PC in the development stage or to a navigation or control unit at real conditions (Takács, 2007).



From above From under

Figure 3: The prototype of the sensor.

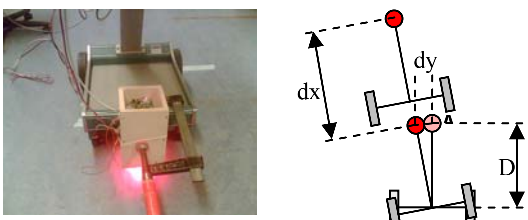
3.3 Testing, Error Measurement

To measure the errors of the sensor we mounted it on a test platform (figure 3/a) and performed some experiments.

The first group of tests analyzes the dependence from the texture of the floor and from the height over ground. The experience showed that the sensor is really insensitive to the height (thanks to the telecentric optics) but unfortunately it sometimes misses on shining or totally homogeneous surfaces.

This property is inherited from the mouse-chip of the cheap optical mice. Laser equipped optical mice might be better from this aspect. Therefore using the mouse-chip of a laser mouse presumably solves this problem.

With the second type of the tests we measured the accuracy of the sensor. First we determined the model of the platform then we executed the so called unidirectional square-path test (Borenstein, 1996). The model of the navigating agent and the connection between the motion and the measured sensor values is shown on figure 3/b. The y component measures orientation change, the linear dislocation appears in the value of the x component.



a.) b.)

Figure 3: The test platform and its model.

By normal conditions the measured error was relatively small in the course of movement around the square. 4,5 meters of travel yielded 0,01-0,02 meters of the inaccuracy (meaning 0,3% overall error).

It is important to add that slip free wheel contact was supposed. In case of slippage the error grew dramatically, the inaccuracy could even reach the 0,3-0,4 meters (7% error). It was caused by the appearance of linear dislocation in the value of the y component, and the ratio between the linear dislocation and the orientation change can not been determined.

It seems to be a paradox situation since this optical navigation sensor was developed for replacing the wheel encoder based odometry, however we faced the same problem (the inaccuracy from the slippage of the wheels). But as opposed to the odometry, out experiences showed, that this method has a simple and effective solution. By using two optical sensors, a platform independent an accurate dead reckoning navigating sensor-system can be developed that works well under real conditions (wheel-slippage, travel over uneven floor etc.) too.

4 ALTERNATIVE APPLICATIONS

4.1 Electronic Stability Control of Vehicles

One of the most critical areas of stability systems (ESP, ABS etc.) is the accurate measurement of the dynamic state of the vehicle. Probably the most important state variable is the slip angle of the moving vehicle. It is needed for the calculation of the force between the wheels and the ground and also for the exact description of the motion-state.

Presently used measurement procedures of the slip angle are in general very expensive therefore it they are not really usable in mass production (Kálmán, 2005). Hence it is necessary to use estimation methods to provide the value of the slip angle. Unfortunately these procedures can not provide accurate results (Bári, 2006).

This optical sensor provides an effective and cheap solution to solve the problem of the slip angle because it can measure (instead of estimation) directly the slip angle, the ground velocity in 2D and other important motion information. Therefore it can be an additional sensor of any vehicle handling enhancement system, for example ABS or ESP. Naturally for utilization in the automotive industry it is necessary to fulfil numerous standards and reliability requirements, which will not be discussed in this paper.

4.2 Linking Vehicle Dynamic Properties into World Map Building

Another interesting area of application is a multi sensor navigation unit of a mobile robot or automated vehicle. By fusing information from the optical correlation sensor and other sensors measuring the vehicles inner state - such as acceleration, tilt, wheel speed, GPS sensors - very precise dynamical information can be obtained. This information can be used to build a world map that contains information not only about the environment but also its effects on the dynamical behaviour of the robotic vehicle. The optical sensor plays an important role in this unit because it is able to measure true ground velocity relative to our vehicle, making us able to determine wheel slippage and slip angle.

Intelligent mobile robots navigate around in their environment by gathering information about their surroundings. The most common approach is to use ranging sensors mounted on the robot to form occupancy grids or equivalent. Other approaches avoid this metric division of space and favour topological mapping. By combining these mapping techniques it is possible to form a hierarchical map that has the advantages of both methods while some of the disadvantages can be avoided (Thrun, 1998).

Occupancy grids classify the individual cells based on range data and possibly other features such as colour or surface texture or variation. This becomes very important in outdoor mobile robotics when the robot needs to distinguish between real obstacles and traversable terrain. An extreme case is given by navigation in a field of tall grass. The elevation map will represent the scene as a basically horizontal surface above the ground level; that is, as a big obstacle in front of the vehicle. It is apparent that only by integrating the geometry description with terrain cover characterization will a robot be able to navigate in such critical conditions (Belluta, 2000).

Topological maps describe the world in terms of connections between regions. This is usually enough indoors, or in well structured environments, but when travelling through more complex terrain a different representation might be necessary. For example a sloping gravel road or sand dune may only be traversable at a certain speed or only one way, up or downwards. By applying information from the inertial navigational unit, such as slope angle, wheel slippage, actual movement versus desired movement, these characteristics can be learned (or used from apriori information) and the connections of the topological graph can be updated accordingly.

Terrain characteristics (and those of our vehicle) determine the maximum safe speed, braking distance curve radius at a given speed, climbing manoeuvres etc. It is obvious that the more information we have about a certain region we are planning to travel through, the more driving efficiency we can achieve, as it is generally unsafe to drive at high speed through bumpy terrain or make fast turns on a slippery surface. By incorporating the data from the navigational unit into the world map, we can associate driving guidelines to a given map segment. Also on the higher, topological level - using apriori information - we can identify the type of the terrain for a given point of our topological graph, as office environment, forest, urban area, desert etc. By doing so, we narrow down our choices when making decisions about terrain coverage. For example it is unlikely to encounter sand, water or foliage in an office environment. If we know the type of terrain ahead we can make a more accurate estimate of the driveability of the area thus increasing driving efficiency.

In this section a hierarchical map making method was proposed which uses data from a multi-sensor navigation unit that supplies information about vehicle dynamics. This unit heavily relies on the optical correlation sensor described in the preceding sections. By measuring wheel slip and vehicle slip angle we are able to associate drivability guidelines such as safe speed, friction coefficient, minimal driving speed etc. to a given map segment or type of terrain. A higher level of environment recognition was also proposed: based on apriori information, or sensor data the vehicles control system decides the type of environment (e.g. office, forest, desert) the robot traverses at the time, and changes the probability of terrain types, characteristic of the type of environment, thus simplifying terrain classification.

5 SUMMARY

In the previous sections we presented an optical navigation sensor which measures motion information (velocity, dislocation, slip angle) without ground contact.

An alternative dead reckoning technique is proposed in section 3, that yields superior accuracy compared to wheel encoder based methods. In the first part a short overview of principle (e.g. optical flow) is given followed by the description of our experimental setup. Experimental results are given in the last part. Conclusions: the current system should be made platform independent by using two rigidly linked sensors, use of laser mouse chips is recommended to overcome the problem of texture dependency.

Finally examples of alternative application areas were presented: slip angle measurement for the safety systems of vehicles and hierarchical map building with additional driveability information.

As a conclusion we can say that the device and dependent methods presented here can serve as cheap and accurate alternative solutions to numerous problems of the robot and automotive industry.

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