Sborník vědeckých prací Vysoké školy báňské - Technické univerzity Ostrava
číslo 1, rok 2008, ročník LIV, řada strojní
článek č. 1593

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3D DATA CAPTURING SERVICE ROBOT PROTOTYPE

PROTOTYP SERVISNÍHO ROBOTU PRO ZÍSKÁVÁNÍ 3D METRICKÝCH DAT

Abstract

The article presents service robot prototype intended for gathering and processing 3D metric data in real time, including monitoring tasks. Shape, function and basic characteristics of the prototype rise from the demands for service robots customized for applications in urban areas. Robot can fulfill a batch of service task with specialization on 3D metric data capturing and monitoring in the outdoor environment. MSC/ADAMS simulations and analysis will be performed on the robot model and will be compared with real life use performance. Prototype's operational and control systems will be tested as well as riding parameters and video transmission, etc. Testing will be done on specially crafted polygons during performance of the selected service tasks.

Abstrakt

Článek prezentuje vyrobený prototyp servisního robotu, který je určený pro získávání a zpracování metrických 3D informací v reálnem čase včetně provádění monitorování. Tvar, funkce a základní charakteristiky vyrobeného prototypu vycházejí z požadavků na servisní roboty pro aplikace v městském prostředí. Robot může plnit řadu servisních úloh se zaměřením na pořizování 3D metrických dat a monitorování ve vnitřním i venkovním prostředí. Na 3D modelu budou prováděné analýzy v systému MSC/ADAMS. Na vyrobeném prototypu budou ověřovány výkonové a řídicí subsystémy, jízdní vlastnosti, přenášení obrazu apod. Testování bude uskutečněno na vyrobených polygonech a při realizaci vybraných servisních úloh.

1 INTRODUCTION

Mobile robots specified for service task performance are equipped with camera system for navigation of robot movement and with a pair of cameras set for 3D metric data capture. Robots are also equipped with environment recognition sensor, thermal camera and light sources, etc. Operation of service robots for 3D data capture depends on service task. In the most cases manual control by operator is used. Locomotion mechanisms are mostly based on wheels, crawlers or hybrid, and hold an extension module with cameras and the other fittings [1, 2, 3]. The extension module with cameras may be hidden inside the bogie frame during robot movement in the field, when measurements are not captured. We talk about "transport position" that protects the cameras from damage during instable or collision conditions. Furthermore there is an advantage of lowering height total of the mobile robot regarding to better robot transmissivity in tunnels or other low profile places. The robot has to stop and set the camera extension to "working position" during 3D metric data capture. Axis of both cameras should be in parallel and horizontal position during measurements. Setting to the horizontal position is done by a standalone module fastened to the frame of locomotive mechanism. Extension module carrying the cameras has to have enough degrees of freedom (at least two) to be able to

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achieve the required position. Achievement of the required position of the cameras is controlled by elevation sensors. Smaller constructions of wheel or crawler locomotion mechanisms are used for indoor environments. Solution with use of crawlers counts with the possibility of movement on the steps. For outdoor applications we have to choose locomotion mechanisms able to pass obstacles of 100mm at minimum [5, 6, 10, 11].

2 MODEL OF 3D DATA CAPTURING SERVICE ROBOT PROTOYPE

A four wheeled robot has been designed and manufactured at the Department of Robotechnology. The impulse for the realization of four wheeled robot for 3D metric data capture was a demand for a smaller robot suitable for urban areas, able of capturing this type of data. The prototype of four wheeled robot has at first been exactly modeled in Pro/ENGINEER system. A chassis base of the locomotion mechanism comes from RC model kit. The locomotion mechanism chassis has been commercially obtained and included load-bearing frame together with the front and the rear axletree. Side turning of the front wheels is realized with use of Ackermann driving principle. The rear axletree is equipped with a planetary differential gear. The rear set of the locomotion mechanism has been modeled according to the real dimensions of each part. Design and modeling of the propulsion system has followed, including the extension plate equipped with camera subsystems and a control computer. 3D model of the robot from two perspectives is shown at Figure 1.

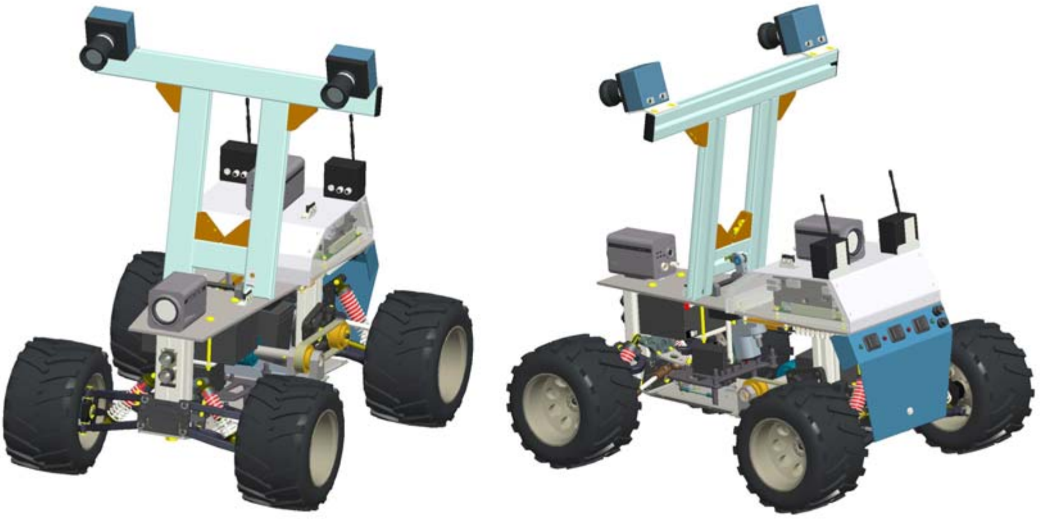

Fig. 1 3D model of four wheels robot modeled in Pro/ENGINEER

The complete model of the robot modeled in Pro/ENGINEER will be transferred into MSC/ADAMS system. MSC/ADAMS will be used to run analysis aimed on performance of the power subsystem and robots riding parameters at the obstacles built on the testing polygon. The evaluation of 3D model of the mobile robot will recursively allow the realization of modifications like for an example a change of some of components shape, change of motors or change of robots gravity axis to achieve better stability, etc. The testing polygon is formed of a set of different panels with configurable obstacles. The panels can be set to various configurations to simulate various terrain types.

3 TAILOR-MADE 3D DATA CAPTURING SERVICE ROBOT PROTOYPE

The four wheeled robot prototype we made is conditioned for 3D metric data capture at indoor and outdoor environment. It is controlled by an operator with use of RC set. Control commands and video signals are transmitted wirelessly and will be further innovated. The overall look at the tailored robot prototype is shown at Figure 2. The robot has been presented at FOR INDUSTRY 2008 fair in Prague.

Fig. 2 Prototype of four wheels robot for 3D data capture

The locomotion mechanism is performed by the four wheeled variant with Ackerman's type of driving. A spring suspension of the front and the rear wheels with dumping is prepared for a gross weight of 15 kg. The wheels are of 200 mm diameter and the locomotion mechanism can pass over the obstacles up to 70 mm height, without the risk of getting stuck at the frame. A ground length of the robot is 570 mm and width is 400 mm. The payload is formed by a complex extension module. The rear axletree is equipped with a planetary differential gear. Side turning of the front wheels is realized with use of a servo motor. A DC engine with a gearbox has been selected for propulsion of the rear axletree. The gearbox output axle can hold 85 Nm for short time. This torque allows the robot to pass trough broken outdoor terrain without much problems. The transmission of the torque to the rear axletree is done with use of a gear belt. The powering of the rear axletree engine as well as the powering of the extension module arm is from 12V battery. Another battery is used for powering of the control PC placed at the upper plate of the extension module as well as for powering of the other components.

The Extension module is composed of a load-bearing plate that is fastened to the frame of locomotion mechanism with use of columns. The plate is equipped with a simple arm built of aluminum profiles. The arm holds two cameras for 3D metric data capture. In case of need it is easy to place a limelight between the cameras. Position of the arm is realized with use of a DC motor and a movement bolt. The movement bolt transforms the rotary motion to the linear motion for the camera arm positioning. The rotary angle of the arm comes from a possible position of the robots locomotion mechanism during its movement in raw terrain. The processing of the captured images is done on software base and allows for compensation. Therefore it is not mandatory to set the axes of both camera lenses to the horizontal position. A partial compensation of camera's positions will be achieved by appropriate rotation and setting of the whole robot, together with tipping of the arm. This is the way of setting the cameras ready for the image capture. The Extension module has only one freedom of movement and therefore is noted for its simpleness. The arm can be set to a different span width at any time. That is very useful for easy change of photogrammetric base parameters. An advantage of the arm is also in possibility to quickly fasten any complementary equipment necessary for performance of selected service tasks. For example it may be another camera used for additional operator orientation during the robot navigation to the desired direction.

3.1 3D capturing subsystem

3D data capturing system has been taken and further modified from a previous grant partially solved by authors, which was funded by Grant Agency of Czech Republic. Lens shutters of the cameras making stereo pair images of the measured object are controlled from the operator station with use of touch screen tablet PC (Figure 3.). Processing of the images is done directly on the computer placed at the robot. This is due to need of parallel processing of both the images and computer power demands necessary for capture of both the images at the same time (two separate Firewire controllers are mandatory to handle data streams). Accuracy of the 3D data captured depends on measured object distance. With the photogrammetric base and camera types we use, best results are achieved at 10 m distance – in this case it is lower then 15 mm.

Fig. 3 Operators station – Tablet PC with touch screen

For calibration of the photogrammetric stereo base, and for carrying out the photogrammetric measurements in the scenes, our own software [4] has been developed at the Department of Informatics, VSB-TU Ostrava. The calibration of the base includes determination of the intrinsic parameters of both the cameras (the focal lengths, positions of the principal points, coefficients of non-linear distortion of the lenses), and the extrinsic parameters of the camera pair (the vector of translations, and the vector of rotation angles between the cameras). For calibration the base, a chessboard calibration pattern is used [4].

The software realizes the calibration in the following four steps:

- ☐ Creating and managing the set of calibration images (the set contains pairs of images captured from the cameras or read from files),
- ☐ automated processing of the images of calibrating patterns (automated finding of the chessboard pattern and the calibrating points in it),
- ☐ preliminarily estimating the intrinsic and the extrinsic parameters of the base,
- ☐ final iterative solution of all the calibration parameters. For the initial estimation of the parameters, the method proposed by Zhang [7,8] is used.

Both the radial and the tangential distortions of the camera lenses are taken into account. The final solution is done by the minimization approach. The sum of the squares of the distances between the theoretical and the real observed projections of the calibration points is minimized by the Levenberg-Marquardt method. In more details, the process of calibration of the cameras may mathematically be described as follows. Suppose that m images of the chessboard calibrating pattern are available. The pattern contains n calibrating points whose coordinates (in the plane of the pattern) are known. Let xj stand for the coordinates of the j-th point, and let uLij, uRij be the coordinates of the projections of this point obtained in the i-th image by the left and the right camera, respectively. We use a to denote the vector containing the values of all the intrinsic camera parameters. The subscript (either L or R) distinguishes between the left and right camera. The vector p contains all the extrinsic parameters of the camera pair, namely, the mutual translation and rotation between the cameras. Let us finally introduce the notation proj (x, a, p) for the projection of a point with the coordinates x. The projection is fully described by the parameters a and p. The process of calibrating may now be formulated as the following optimisation task [4]:

$$\min_{\mathbf{a}_\mathrm{L},\mathbf{a}_\mathrm{R},\mathbf{p}} \sum_{i=1}^{m}\sum_{j=1}^{n}\left(\left\|\mathbf{u}_{\mathrm{L}ij} - proj(\mathbf{x}_j,\mathbf{a}_\mathrm{L},\mathbf{p})\right\|^2 + \left\|\mathbf{u}_{\mathrm{R}ij} - proj(\mathbf{x}_j,\mathbf{a}_\mathrm{R},\mathbf{p})\right\|^2\right) \qquad (1)$$

After the stereo base has been calibrated, the photogrammetric measurements may be carried out. The software makes it possible to measure the coordinates of points, the distances and the angles in the scene.

Naturally, the problem of determining the coordinates (in a certain coordinate system) plays the crucial role in all the mentioned measurements. Let **x** denote the vector of coordinates of a point of interest, and $\mathbf{u}_\mathrm{L}$, $\mathbf{u}_\mathrm{R}$ let be the coordinates of its projections observed in the left and in the right image, respectively. The coordinates **x** are determined by the minimisation approach that resembles to that one mentioned in the previous paragraph for calibration. Using the same notation as before and taking into account that the values of the vectors $\mathbf{a}_\mathrm{L}$, $\mathbf{a}_\mathrm{R}$, and p are known after the calibration has been done, the problem of finding the unknown coordinates of the point of interest may be solved by the following minimisation (**x** is determined in the coordinate system of the left camera) [4]:

$$\min_{\mathbf{x}}\left(\left\|\mathbf{u}_\mathrm{L} - proj(\mathbf{x},\mathbf{a}_\mathrm{L},\mathbf{p})\right\|^2 + \left\|\mathbf{u}_\mathrm{R} - proj(\mathbf{x},\mathbf{a}_\mathrm{R},\mathbf{p})\right\|^2\right) \qquad (2)$$

The measurements that are performed by the operator may be completed with explaining annotations. The measurements form a set that may be recorded into a file and viewed again. The software also offers the means for later editing the set and for exporting the measured data. A pair of fire-wire cameras may be served by the software, which makes it possible to capture the images both for calibrating and for measuring also directly from the cameras.

3.2 Power computing system

The computing system is based on Arcon Apollo embedded computing platform, that provides very high computing power, has relatively small dimensions for the power and interfaces possible and at the same time has low energy requirements. Due to 3D software development reasons (Microsoft x86, 32 bit) we use Microsoft Embedded XP as an operating system. We are taking use of its modularity and scalability, so the system core image together with all the applications is smaller then 200 MB. The selection of this “similar to desktop” system is also very useful for easy expansion of supported tasks and functions – standard applications can be used directly or with only minimal customization. The basic parameters of the computing unit are shown in Tab. 1.

Tab. 1 Operators station – Tablet PC with touch screen

Parameter	Description
Platform	EBX
CPU	1.6GHz Intel® Pentium M CPU
RAM	1 GB
Interfaces	PCI, Ethernet, CF, IDE, USB, RS323, Firewire and other
External memory	4 GB Flash HDD (CF card)
Operating system	All supporting Intel platforms – Windows, Linux
Power consumption	5-15 W during operation

Communication and control system is based on several wireless technologies. In fact, we are using three separate technologies. For movement control of the platform and of the rotary arm, we use R/C interface that gives the operator maximal sensitivity and freedom of move together with long range even in problematic environments. Visual data from navigation cameras are transmitted with use of analog radio system. The reason for analog system is again in long range in problematic environments. All other communication is done by 802.11 b/g (Wi-Fi) technology. Robotic platform is equipped with Wi-Fi modified accesspoint that ensures multiuser access (global with use of Internet) to the resources (computer unit, sensor systems, etc.) and to data stored on-board. It may also take some basic control functions in case of main computer failure. We are using standard TCP/IP protocol and standard services over it. The computing unit runs secure ftp server (FTPS), SSH server, http server (web) and two types of remote desktop sharing that allow direct control and configuration of the operating system and system environment. Multiple remote users may access stored imagery or see the view of "robots eyes" and cooperate this way. Security of data transfers is managed by encryption algorithms implemented in hardware and software layers of wireless networks (WEP) and TCP/IP protocol and services over it (SSL, SSH).

The system is equipped with several positioning sensors like an electronic compass to get direction of camera system, GPS receiver to get absolute position if it is possible (supporting DGPS and EGNOS) and IMU (inertial navigation unit) for positioning indoors. We are in early state of shifting the robot control from manual operation to the semi-autonomous movement ability with use of Crossbow mNAV "inertial cube" (Fig. 4).

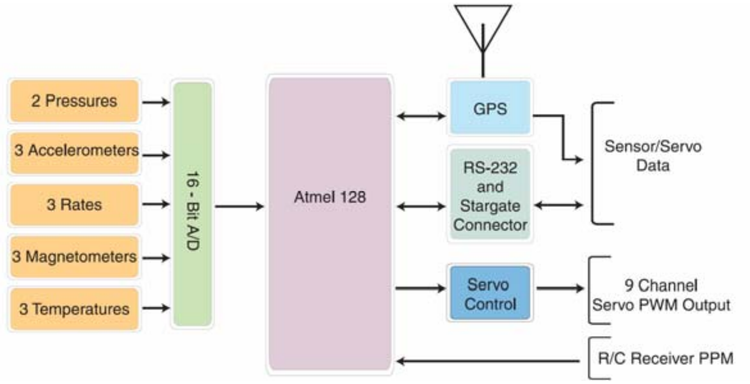

Fig. 4 Crossbow mNAV unit scheme (www.xbow.com)

3.3 Driving control of the prepared prototype

The four wheel variant shown at Figures 1 and 2 has two propelled wheels (rear) with planetary differential. Front wheels are not propelled and are used for steering. Turning of the wheels to the desired angle is done with use of servo motor. As shown on Figure 5, by prolonging centers of the wheel axes we get their intersection (point P_1) which creates a virtual center point around which rotates the locomotion mechanism (angular and centrifugal momentums are omitted). Circumferences of the circles with tangents formed by velocity vectors are achieved by that.

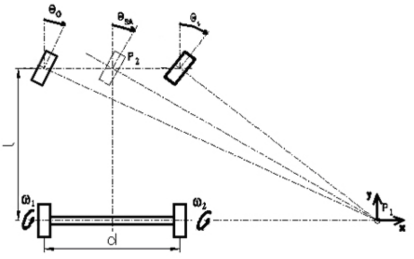

Fig. 5 Kinematic scheme of Ackermanns type of steering

To determine the rotation angle of steering wheel we use Ackermanns equation:

$$\cot g\Theta_i - \cot g\Theta_0 = \frac{d}{l} \tag{3}$$

where:

Θ_i .. *is relative rotation angle of the inner wheel* $\left[{}^\circ\right]$,

Θ_0 *is relative rotation angle of the outer wheel* $\left[{}^\circ\right]$,

l .... *is a distance between front and rear axletree* $\left[\mathrm{mm}\right]$,

d ... *is width between wheels on propelled axletree* $\left[\mathrm{mm}\right]$.

For better imagination we may set the rotation angle Θ_{SA} connected with imaginary wheel placed in the reference point P$_2$, as shown at Figure 3. The angle Θ_{SA} may be expressed with use of the inner and the outer angle of wheel rotation (Θ_i or Θ_0)

$$\cot g\Theta_{SA} = \frac{d}{2\cdot l} - \cot g\Theta_i \tag{4}$$

or

$$\cot g\Theta_{SA} = \cot g\Theta_0 - \frac{d}{2\cdot l} \tag{5}$$

Ackermanns steering gives a relatively good results in this case for wide spectrum of the tracks on a flat terrain without obstacles as well as on raw terrain [9]. An example of a simple testing terrain within MSC/ADAMS system is shown on Figure 6. The first testing of the model behavior (from Figure 1) was performed on this terrain. As an example (Figure 7.) we can mention a graph of robots parallel axes differences in straight driving direction across the obstacles in various robot movement speeds (v=0,3 m/s, v=0,5 m/s, v=0,7 m/s).

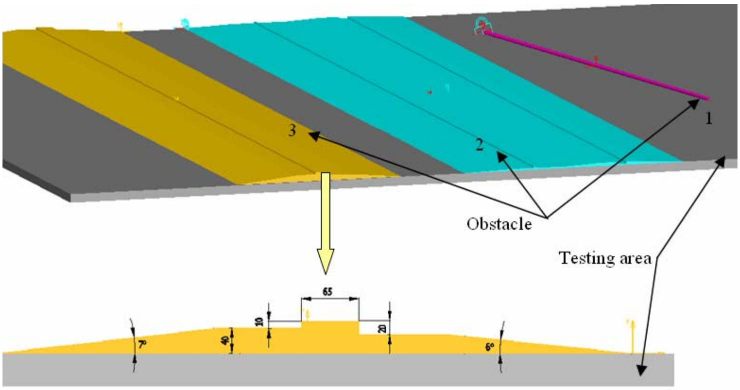

Fig. 6 Testing terrain with obstacles

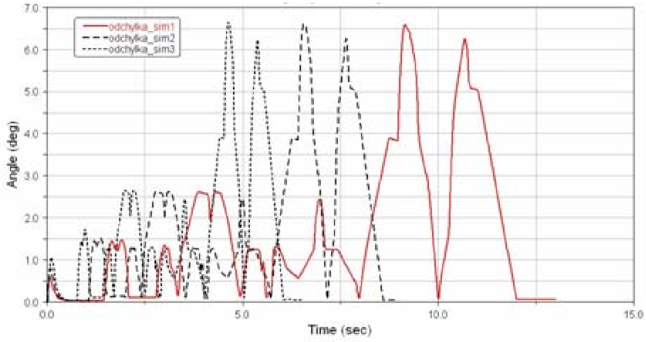

Fig. 7 Simulation of robots parallel axes differences

4 POSSIBLE PRACTICAL APPLICATIONS OF THE PROTOYPE

From the point of view of practical application we can apply the robot with 3D capturing device for the following service tasks:

- ☐ Gathering 3D metric data during survey of human inaccessible areas
- ☐ Gathering 3D metric data during survey in unknown terrain
- ☐ In chemically or other way contaminated environments (after necessary housing modifications)
- ☐ Various security related tasks
- ☐ Size determination in indoor and outdoor environments
- ☐ Specific tasks in other fields

In the area of civilian use this robot may help with labor intensive tasks measurements of shape complex objects. Robot can take place in the areas inaccessible or dangerous for human presence. We plan to modify the robot for several different tasks in the future. Extension camera module can be applied on different type of locomotion mechanisms. Last but not least these robots can be very helpful during rescue operations. In such case we have to be ready for special environments, including explosion risk areas.

5 CONCLUSIONS

The preliminary test has shown that our prototype is in general suitable to perform the specified service tasks. We will continue the tests on the polygons as well as in real life environments. Among other we will test the influence of various environments on control subsystems and on video signal transmission. Practical results will be continuously compared with characteristics calculated from the 3D model done with use of MSC/ADAMS. This will be useful to determine how exact the modeled and practical characteristics match. This article presents knowledge gained during solution of grant project MPO Tandem no. FT-TA3/014.

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