Ackermann mobile robot chassis with independent rear wheel drives

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***Abstract* — This paper describes four-wheeled robotic chassis of the robot Bender II utilizing Ackermann steering and independent rear drive units. Hardware and software implementation details as well as practical experiences of this approach deployment are presented.**

***Keywords* — Electrical Drive, Mechatronics, Motion control, Robotics**

I. Introduction

Design process of a mobile robot includes many concept decisions to be made in order to choose a proper solution of each construction aspect keeping in mind often contradictory requirements. One of the most important is the selection of the chassis type.

There are many different chassis concepts usable for a mobile robot [1]. The most common is probably the differential drive system [2] for its simple utilization and high maneuverability, although it does not excel in efficiency and can damage less resistant surfaces while turning. Another type, the omnidirectional chassis [3], provides excellent maneuverability, but requires a flat solid surface to ensure good behavior and prevent uncontrollable motion.

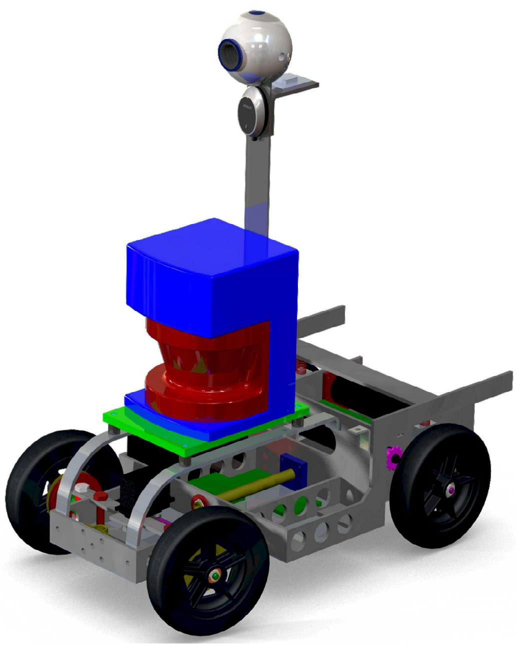

Fig. 1. Mobile robot Bender II 3D model

While the foregoing chassis types are advantageous for use in mobile robotics, the real-world vehicles (except some working and military machines) make usually use of a four-wheeled chassis with the Ackermann steering. It offers the most efficient operation and good behavior at high speeds, but also relative low maneuverability sequent to its nonholonomic constraints.

II. Bender II platfom description

Bender II is a mid-sized wheeled mobile robot designed at the Institute of Solid Mechanics, Mechatronics and Biomechanics as a platform for autonomous delivery and related algorithms development. It is 60 cm long, 30 cm wide and weighs about 25 kg.

Utilization of the Ackermann steering together with independent rear drives in Bender II is a result of an effort to build a system conceptually similar to real vehicles (as for example the path planning algorithms should be designed and tested on a robot with at least comparable maneuverability) but not suffering from the loss of traction in case of one wheel slippage (common for vehicles fitted with the mechanical differential). In the further text, our modification of a classical automotive chassis is described.

A. The swinging rear axle

In order to simplify the overall construction, several changes to the classical automotive chassis ware made. The largest one applies to the wheel suspension – as the common independent wheel suspension is a complex mechanical structure and is in piece quantities hard and expensive to manufacture, it has been decided to use a swinging rear axle. This solution allows the chassis to deal with terrain irregularities (through the chassis torsion) and stay mechanically simple at the same time.

Realization of the swinging rear axle is quite straightforward. The body of the robot is divided into two parts, the rear (holding both drive units) and the front (carrying the rest of the equipment). These two parts are connected by a shaft housed in bearings that enables the rear axle to swing. This method is usually used when heavy loads make the classic independent suspension impossible. The Bender II platform is also designed to carry "heavy loads" (such as a laser scanner and other sensory equipment). A torsional spring is placed between the front and the rear part to avoid beats and for better stability. Figure 2 shows, how the swinging axle works. The rear part of the robot can rotate relatively to the front part.

The rear axle has no mechanical differential fitted – the drive units of both rear wheels are independently controlled allowing the master control system to set different velocities for each wheel. In dependency on the actual steering angle and the desired forward speed the wheel velocities are computed and set to the drive units. The particular algorithm is described below.

Each drive unit consists of the Maxon RE40 DC motor with a 43:1 planetary gearhead and a chain transmission to the wheel (1.5:1 ratio). The motor is controlled by a specially designed speed controller communicating with the master computer using a RS-485 bus. This two drive units provide total power of 300 W and total constant torque of 30 Nm (wheels have 15 cm in diameter). The power is supplied by two 12 V/7 Ah sealed lead-acid accumulators.

B. *Ackermann streering*

Ackermann steering (also known as kingpin steering) solves the difference of angles between steering wheels during vehicle turning. This difference is caused by the fact that each wheel follows a different radius, so that the inside wheel has to be tilted a little more than the outside wheel. This principle radically reduces tire slippage (that is important especially at higher speeds). It is realized by double pivoting system, where the pivots are at an angle. The angle has to assure that the kingpin axis, end of the pivot and center of the rear axle are in line (as shown on Fig. 3). It is possible to detent the static toe-in by a threaded rod in order to achieve better driving behavior.

According to these diagrams, the kingpin is placed in the center of the wheel; that can be very difficult or even impossible to achieve (from the construction point of view), mainly when common commercially available off-shelf wheels are used. The Bender II front wheels center of rotation is placed approximately 50 mm off the wheel center.

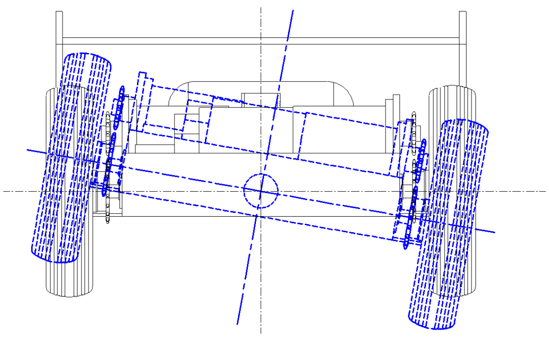

Fig. 2. Swinging rear axle of the Bender II

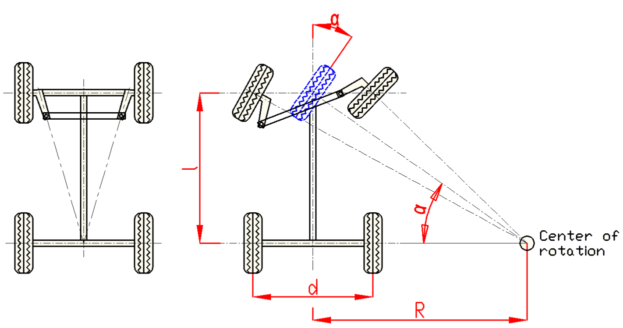

Fig. 3. Ackermann steering principle

III. Software differential

As already discussed in the previous chapter, angular speeds of the rear wheels (or motors) are controlled independently by the software differential. Individual motor angular speeds must be described in dependence on the steering angle α. It is needed to introduce angular speed of a virtual motor fitted in the center of the robot:

$$\omega = \frac{v}{r} \cdot i \tag{1}$$

where v denotes forward speed, r is wheel radius and i the total gear ratio between the motor and the wheel. From the Figure 3 it is possible to derive the relation between the steering angle α and the curve radius R:

$$R = \frac{l}{\tan \alpha} \tag{2}$$

where l is the wheel base of the chassis. The angular speeds of the motors are then dependent on the ratio between the wheel spacing d and the current curve radius R:

$$\omega_L = \omega \cdot \left(1 + \frac{d}{2 \cdot R}\right) \tag{3}$$

$$\omega_R = \omega \cdot \left(1 - \frac{d}{2 \cdot R}\right) \tag{4}$$

where ω_L (ω_R) is the left (right) motor angular speed.

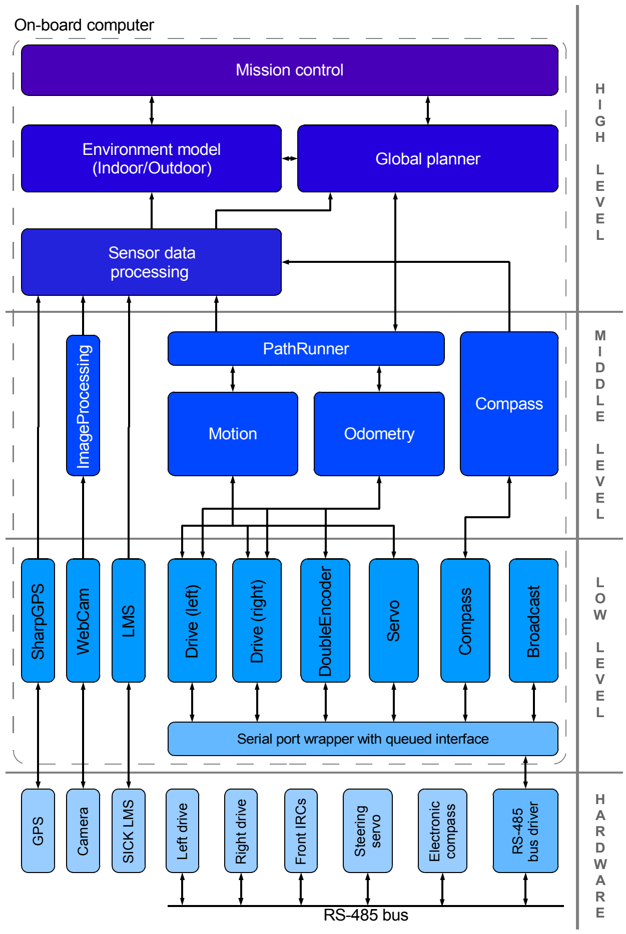

Fig. 4. Bender II software architecture

All quantities used to describe any parameter of the robots turning in this paper are introduced following a simple convention – turning to the right implicates positive sign of the value, turning to the left is represented by negative sign. A similar rule is applied to velocities – positive speed means forward movement, negative implies reversing.

A. *Implementation of the software differential*

As the software architecture scheme (Fig. 4) shows, there is a module *Motion* that lies on the top of the low-level modules (individual hardware devices interfaces). This module is an entry point for the higher software layers to control the motion of the robot. It encapsulates the software differential and provides two public methods – method `Go(speed, direction)` used to drive the robot at the desired speed to the desired direction and method `Stop()` to halt the robot.

The internal structure of the SW differential code follows the equations presented previously. The algorithm firstly converts the desired robot speed to the angular speed of a virtual centered motor. Then the desired curve radius according to (2) for a non-zero direction angle is computed (zero has the meaning of a straight movement and matches an infinite curve radius).

The next step is already to calculate the individual motor angular speeds according to (3) and (4). This can be done only when a non-infinite value of the curve radius is provided. Otherwise the differential algorithm is skipped and both wheels are driven at equal angular speeds.

The *Motion* module has now all information to order the steering servomotor and the drive units to set the currently computed values. This procedure repeats every time the upper software layers decide to change desired speed or direction of the movement.

IV. Practical experiences

The robot Bender II has been thoroughly tested during both indoor and outdoor localization/navigation algorithms development using the described architecture.

It has been found that the chassis of our robot behaves well under various conditions. The independent rear wheel drives system does not suffer from the complete loss of traction in case of one wheel slippage, as both drive units hold their preset speeds independently. The robot is thus able to drive through surprisingly hard terrains and still behave well and economically on the road.

While the ratio of the rear wheel angular speeds is dependent only on the steering angle and not on the unstable adhesion of individual wheels, the robot is not prone to under- or oversteering – the Ackermann steering is supported by the rear wheel speeds ratio.

The only disadvantage of the presented independent drive units architecture (apart from obvious problems arising from using two motors, two gears and two controllers instead of one) is that the chassis becomes less controllable in case of misbehavior of one of the drive units. This happened several times at the beginning of the chassis testing and was caused by communication problems. Such problems can be avoided by using a single controller driving both traction motors, when a possible communication failure would not cause discrepancy in wheel angular speeds.

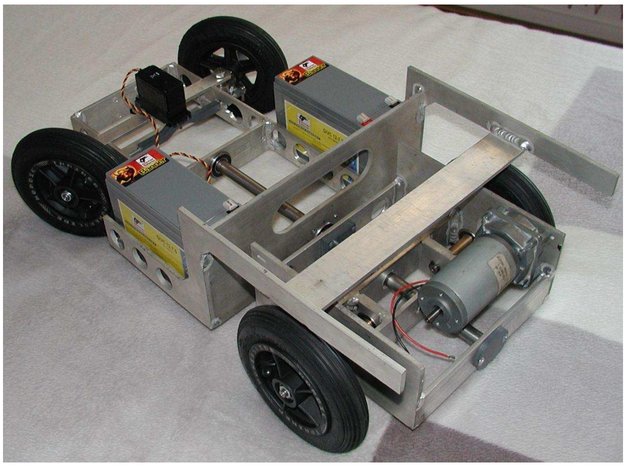

Fig. 5. Bender II chassis with a testing DC motor fitted

V. Conclusions

This paper describes the use of the Ackermann steering together with independent rear drive units controlled by a software differential algorithm. Utilization of this solution was selected in order to provide an energetically effective yet robust mobile robotic platform.

Our approach has been proven to be functional under various conditions during operation in both indoor and outdoor environments. The use of independently driven rear wheels with the automotive chassis is commendable when other type of chassis is unemployable and desired environment would bring problems with the mechanical differential.

Acknowledgment

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