Adaptive Control of a Virtual Mini Robot with Autonomous Displacement Using a Virtual Sensor System

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Abstract: The paper presents the latest version of a family of optoelectronic sensors used for the control of mini robots without embarked sensors. The optoelectronic sensors are based on the concept of virtual sensor. The last section of the paper focuses on the technical solution developed for the transfer of the light source attached to the mini robot on the tracking and control equipment, using a laser directed to a reflecting sphere attached to the mini robot.

Keywords: optoelectronic sensor, virtual sensor, rotating mirror, stereoscopic base, mini robots.

1. INTRODUCTION

In the course of time, a family of optoelectronic sensors able to follow a light spot was developed and studied in the frame of the Chair of Mechatronics and Precision Mechanics, Băcescu et al. (1995), Băcescu et al. (2002), Băcescu (2002), Bucşan et al. (1998). These sensors, mounted on equipment that materializes a stereoscopic base, allow establishing the spatial position of a light source placed on a mobile object.

If the light source is attached to a mobile robot, the optoelectronic equipment can follow its evolution in the workspace. This feature of the optoelectronic equipment was applied to the remote adaptive control of robots with autonomous displacements.

Due to the interest in robot miniaturisation, a recent research had a mini robot as main subject. In the case of mini robots, the sensorial equipment mounted on their body is often voluminous compared to their overall size, thus miniaturisation is required, Alexandrescu et al. (2011), Băcescu et al. (2010). Sensor miniaturisation is too costly or even impossible. The transfer of the sensorial unit from the mini robot body to an independent tracking and guidance equipment simplifies robot construction, helps miniaturization, facilitates its control and increases displacement autonomy (the own power unit does no more feed the sensor system). Three distinct entities will thus exist in such a configuration: the operation scene, the mini robot and the sensorial equipment, unlike in the usual case, when only two entities are used, due to the fact that the robot body includes the sensorial unit. In this new configuration, the operation (real) scene has to be a priori known, for instance through its topography. The operation scene will thus be doubled by a software equivalent that will represent the virtual scene where a virtual mini robot will move.

2. THE CONCEPT OF VIRTUAL SENSOR

Corresponding to this new mini robot control architecture, component equipments must perform well-defined tasks. The tracking and guidance sensorial equipment establishes at each moment the position of the real mini robot in the real operation scene. Any command of the real mini robot, at a given moment of time, must be preceded by a validated command of the virtual mini robot during its movement in the virtual scene. If the movement of the virtual mini robot displacing itself in the virtual scene leads to a position that cannot be reached in the real scene, the computing unit attached to the sensorial equipment analyses the remaining options using programmable criteria meant to find a possible solution in the virtual scene in order to perform the command and implicitly the correct movement in the real scene.

Such a software structure, able to send to a robot without own sensor system the commands corresponding to the displacement in a real operation scene, was denoted as virtual sensor. The virtual sensor receives and processes the position coordinates of a light source from the real workspace, acquired by the optoelectronic equipment, and connects them to the data from the virtual workspace. The mathematical connecting relations can be simple or more complex, accordingly to the construction and to the functions performed by the optoelectronic equipment. The establishment of the relations that describe the functioning of the virtual sensor considers that the optoelectronic sensor that permanently acquires data delivers at each moment a set of coordinates including also the acquisition time $P_i(x_i, y_i, z_i, t_i)$, $i=1\ldots N$, where N is a priori imposed. These coordinates are in fact the successive positions of the real mini robot for the latest N steps. The interaction with the virtual workspace means computing at each moment the distance between the position of the virtual mini robot related to a set of marks and the coordinates of marks in the virtual space $P_k(x_k, y_k, z_k, t_k)$, $k=1\ldots M$, using the relation:

$$\Delta_{ik} = \sqrt{(x_i - x_k)^2 + (y_i - y_k)^2 + (z_i - z_k)^2} \tag{1}$$

that is equivalent to a virtual three-dimension proximity sensor or, as appropriate, to a virtual contact sensor. In the meantime, any two successive acquisitions from the set of coordinates can be used for establishing the advance direction, by computing the direction cosines:

$$L_i = \frac{x_i - x_{i-1}}{\Delta_i};\ M_i = \frac{y_i - y_{i-1}}{\Delta_i};\ N_i = \frac{z_i - z_{i-1}}{\Delta_i} \tag{2}$$

where:

$$\Delta_i = \sqrt{(x_i - x_{i-1})^2 + (y_i - y_{i-1})^2 + (z_i - z_{i-1})^2}\ ,\ i = 2 \ldots N \tag{3}$$

that amounts to a virtual sensor that outputs the direction of advance.

These simple relations allow evaluating the position of the virtual mini robot in the virtual workspace at each moment using the values of the coordinates and the direction cosines. If a preferred direction is indicated, the direction cosines allow establishing at each moment the angle between the direction of advance of the virtual mini robot and the preferred direction, using the relation:

$$\alpha = \arccos(LL_i + MM_i + NN_i),\ i=1 \ldots N \tag{4}$$

that corresponds to a virtual angle sensor. The set of coordinates allows also the construction of a virtual sensor for the advance speed or acceleration of the mini robot at a given time for i = 2..N:

$$v_i = \frac{\Delta_i}{t_i - t_{i-1}} \tag{5}$$

and

$$a_i = \frac{v_{i+1} - v_i}{t_{i+1} - t_i} \tag{6}$$

If the speed is known for each moment, there is the possibility of anticipating when a certain target can be reached or, as the case may be, the instantaneous speed can be modified in order to reach the target at a certain time.

The virtual sensors can be attached only to a virtual robot corresponding to a real robot through the instrumentality of a virtual space a priori known and stored in the computer memory. The mini robot moving in a virtual space, endowed with virtual sensors of the type presented above, corresponds to the attached real mini robot. This correspondence allows a complex control of the real mini robot without sensors mounted on its body.

In order to allow the interaction between the optoelectronic sensor and the real mini robot, the last one has to be endowed by construction with a number of light points whose positions relative to the trihedron attached to the mini robot are fixed. The reference trihedron has its Oz axis towards its advance direction and its Oy axis perpendicular to the horizontal plane. The Ox axis is the common optical axis of the optoelectronic sensors at a known elevation. Knowing at each moment the position of the punctiform light source and the N previous positions, defined by the acquired values $P_i(x_i, y_i, z_i, t_i)$, allows knowing the evolution of the mini robot and its dynamics and leads to the complete control of this one.

3. DESIGN, STRUCTURE AND FUNCTIONING OF THE OPTOELECTRONIC SENSOR

From the family of sensors developed and conceived by the authors, two optoelectronic sensors based on the same principle can be used for this application. The differences between the two sensors consist in the prices of the conceived equipment and the complexity of the control software.

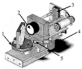

Fig. 1. Optoelectronic sensor that converts the measured time in geometric angle

Fig. 2. Optoelectronic sensor with motor and incremental encoder

A first version, presented in Fig. 1, features a turning mirror 1 driven by the motor 4, an objective 2, a photosensitive strap 3 and three photo-collimators 5. The first photo-collimator (in the rotating direction of the mirror) is an emitter of infrared radiations, the other two are receptors. When the normal on the rotating mirror coincides with the bisector of the angle formed between the first and the second photo-collimator, two counters start. The first counter stops when the image of the light punctiform source, given by the objective, reaches the photosensitive strap. The second counter stops when the normal on the rotating mirror coincides with the bisector of the angle formed between the first and the last photo-collimator. The ratio of measured times represents the ratio between the angle formed by the sight direction of the optoelectronic sensor to the punctiform light source connected to the mini robot and the angle between the first and the last photo-collimator, which is known from the design. In this case, the speed variations of the motor that drives the rotating mirror 1 must not influence the measurements, because the angular speed of the rotating mirror is computed at each rotation through the ratio of the known angle between the second and the third photo-collimator and the difference between the measured times:

$$\omega = \frac{\theta_{constructiv}}{\delta t} \tag{7}$$

where $\Theta_{constructiv}$ designs the angle between the second and the third photo-collimator and δ_t designs the difference between the measured times.

This photo-sensor involves reduced costs, but more complex calculations.

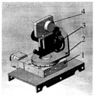

Fig. 5. Subassembly for the steerage of the laser source to a reflecting sphere

The optical gun is composed of two rotating tables 1 and 3 with incorporated angular encoder, a laser 2 and an infrared camera 4. The wavelength of the laser is very close to the wavelength of the spectral sensitivity of the optoelectronic sensor strap. In this case, a reflecting sphere is mounted on the robot instead of the punctiform light source. When the equipment is started, the laser optical gun must be manually fixed on the reflecting sphere of the mini robot. The energy coming from the laser source is diffusely reflected in all directions by the reflecting sphere and can be similarly received by the optoelectronic equipment.

If the position of the rotation centre of the laser source with reference to its trihedron through the constructive coordinates is known and if the position of the reflecting sphere is known, the sighting directions of the laser source are computed with the following relations:

$$\Delta = \sqrt{x_i^2 + (a - y_i)^2 + z_i^2}$$

$$L_{laser} = \frac{x_i}{\Delta},\ M_{laser} = \frac{a - y_i}{\Delta},\ N_{laser} = \frac{z_i}{\Delta} \tag{10}$$

The dimensions of the reflecting sphere are chosen in such a way that its radius be less than half of the displacement increment of the robot. If it is not possible, the laser source has to emit divergently, with an angle that frames the mini robot when it performs at least two increment steps.

If the mini robot becomes so small that even a reflecting sphere cannot anymore be integrated in its construction, it can be painted with a reflecting dye and the equipment will function identically.

6. CONCLUSIONS

The presented optoelectronic equipment was designed and built for experimental researches. The obtained results allowed its successful use for the adaptive control of robots as well as of mini robots without sensorial equipment mounted on their bodies. The specific situations, for well-defined classes of robots and mini robots, allow the design and building of optoelectronic equipment with adequate dimensions, optimized in terms of size and weight.

For very small mini robots, the equipment will also have reduced size and weight. In such cases, a mechanism that would rotate the equipment around the Ox axis and would allow the vertical placement in different positions with reference to the absolute trihedron of the working scene could be designed.

These new features endow the tracking and control optoelectronic equipment with mobility similar to movement of the human eye.

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