AUTOMATION OF WORK IN COWSHEDS USING MOBILE ROBOTS WITH HAPTIC DEVICES SUPPORTED BY VIRTUAL ZONES OF INFLUENCE

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Abstract. The paper presents issues related to virtual zones of influence coupled with a haptics device, which may be used in various types of agricultural mobile robots. These additional virtual zones allow to sense the objects – obstacles before physical contact of the mobile robot with it for to prevent possible collision in the changing work environments. The described control methods were implemented in the Microsoft Visual Studio environment with the use of C++ language and were tested using the Rovio mobile robot. The result of these tests may contribute to the development of new various types of agricultural mobile robots. The directions of further research are indicated in the conclusions of the paper.

Keywords: automation of cowsheds, mobile robots, haptic devices, virtual zones of influence.

Introduction

Everyday activities related to cattle breeding are commonly supported by modern technologies. They are used to relieve the farmer of some monotonous, repetitive work. Currently, stationary and mobile service robots are the most spectacular solutions. They allow, among other things, to automate activities related to: milking cows, keeping the cattle clean, caring and supervision of animals, assessment of the state of health and identification of the oestrus period, with varied nutritional needs at every stage of growth, or if they can, if necessary to gather the feed up [1; 2]. New investments in cowsheds and supporting technologies in specialized farms in the agricultural production sector, despite the still high costs of implementation and exploitation, limiting to direct their own work, allow to reduce additional employments, simultaneously increasing the productivity and improving the health in the herd, cost reduction and multiplication of profits [3]. This paper presents issues related to virtual influence zones coupled with the haptics device, which may be used in various types of agricultural mobile robots [4-7]. The use in such solutions as force feedback allows the operator to sense the object with contacted, controlled and supervised robot at the distance (so-called teleoperation), or to touch the virtual object created in the computer memory as a part of the work environment (so-called virtual reality). In such cases the use of additional virtual zones of influences allows to sense the objects – obstacles before physical contact of the robot with it to prevent possible collision in the changing work environments or resulting from uncontrolled movement of the robot operator.

Haptic devices are hardware solutions of the interface between the computer or robots and the human (system operator). Thanks to the haptic system to remote transmission of information is possible about the type of surface and structure parameters of the observed or controlled objects. These devices have been applied in various fields of science and industries, inter alia in virtual reality technology and telemanipulation (e.g., for robot control) [8]. In virtual reality technology there is a possibility to touch the objects, which are generated in three-dimensional (3D) computer graphics. The user has full interaction with the virtual environment [9; 10]. Haptic device allows to feel the working environment better. The operator receives video and audio information and also additional information through the sense of touch [11; 12]. Currently, solutions applied in the field of medicine in surgical robots are the most spectacular example of utilizing the haptic device technology for telemanipulation purposes. Da Vinci series robots from Intuitive Surgical, Inc. [13; 14], the Polish RobIn Heart surgical robot [15] are examples of such technical solutions. In such systems, the surgeon (operator), separated from the operating area and from the patients themselves, must have information about the type of tissues that the instruments he is operating with are in contact – this is mainly done through a video channel. He must also know, what the current structure of the organ being operated on is (its elasticity or hardness) through a taught sense of touch. In mobile and stationary service robot solutions, thanks to the application of solutions of this type, the operator of the system has access to such information as real weight, elasticity and surface finishing of the processed object in direct contact with the robot's manipulator or with the end effector itself [16]. The directions of further research are indicated in the conclusions of the paper.

Materials and methods

Thanks to the technology described in the Introduction section, it became possible to control robots operating in environments harmful to the operator's health and life, as well as to use them in tasks that would be impossible for a human due to physiological limitations (e.g., inspection of sewer pipes, ventilation ducts and chimneys). When controlling mobile robots, the operator can feel, when the robot hits an obstacle and at what force through control instruments. Such feedback information may contribute to better identification of the environment, when the performance of video systems is insufficient, e.g. due to poor lighting of the camera's field of view. In the case of operation of a mobile robot in environments with a high degree of disorder (e.g., cowsheds in which animals, humans and other robots move freely), it is necessary to secure both mobile robotic solutions as well as the animals themselves against improper operation of the technical system [17]. For this reason, the authors of this paper developed an original concept of control with virtual influence zones assigned to physical objects (mobile and stationary) in the robot's immediate vicinity. The idea of the solution combines telemanipulation techniques with augmented reality. Virtual influence zones coupled with haptic devices perform the role of additional contact buffers in the proposed solution. They send feedback information to the operator, when the mobile robot (potentially the manipulator arm or end effectors) is found within their range. Thanks to this, the operator or mobile autonomous system automating work in the cowshed is able to receive information that may influence the robot control algorithms much earlier. Thus, there is additional reaction time in manual or fully autonomous robot control. Before a collision with the obstacle occurs, the robot will stop or change its planned motion trajectory, or change the current parameters of movement (speed, acceleration, direction of travel).

In the solution presented here, every object found in the work environment of a mobile robot may have several virtual influence zones coupled to haptic device systems [18]. A different type of feedback information may be related to each of these zones as needed, having an influence on the planned control strategy in autonomous mode or on further control by the operator himself in manual mode. Two types of interactions (direct and indirect) during remote control of mobile robots using a haptic device are presented in Fig. 1.

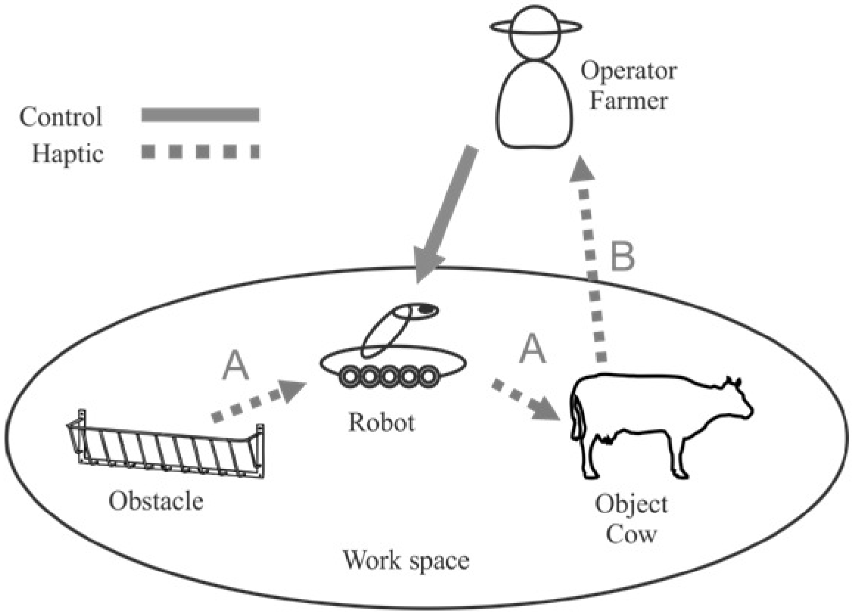

Fig. 1. **Relationships between mobile robot, operator and obstacle over course of control using haptic device:** A – direct interaction; B – indirect interaction

Direct interaction (marked A in Fig. 1) occurs between the robot and obstacle or manipulated object (processed object). This interaction affects the motion parameters of the mobile robot. In the case of permanent obstacles, collision with them is undesirable, and the robot must avoid direct contact with them. Direct interaction of an obstacle with the robot is inadvisable due to potential damage to the robot, objects in the surrounding environment, or both. In this case, the motion trajectory must be selected so as to avoid obstacles over the course of movement. In the case where direct contact occurs despite everything, information about such an event is transmitted to the operator on the screen of the control console.

Indirect interaction (marked B in Fig. 1) is interaction of the manipulated object on the operator himself. The operator has information about the given object originating from processing of information transmitted from the mobile robot's control system. The robot mediates in this type of interaction. The robot enters into physical contact with the object, and information about, e.g., the surface (structure, density) of the touched object is sent to the operator. In this case, it is the robot's end effector, or the robot itself is an interface that mediates in transmission of information to the control device (joystick), with which the operator has direct physical contact. In response to a contact event that has occurred, force is generated on the joystick and felt by the operator's hands. Thus, when controlling a robot, the operator has complete information about the texture (video device), shape, elasticity and type of the surface (haptic device) of the object contacted over the course of control activities [11].

A virtual influence zone (Fig. 2) consists of three layers: 1) audiovisual layer, 2) robot motion parameter change layer and 3) robot movement direction change layer. Each layer provides different feedback. Virtual influence zones may be related to both the manipulated object and the obstacle itself (Fig. 2a) found on the robot's path, or potentially to the mobile robot itself (Fig. 2b), virtually increasing its overall dimensions. The variant, in which the mobile robot, objects and obstacles are assigned their own influence zones, is also acceptable.

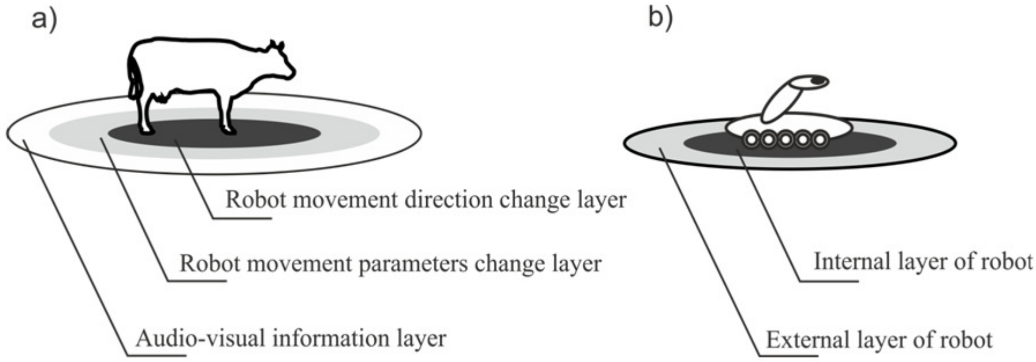

Fig. 2. **Virtual influence zones in division into layers:**
a – obstacle-related zones; b – zones related to mobile robot

In the first case, the mobile robot sends feedback information to the operator, when penetrating into an obstacle's influence zone (e.g., when coming into contact with an animal in the cowshed). Depending on the technical solution adopted, the operator may receive information in the form of an emitted sound warning of the obstacle or in the form of a visual representation on screen, or in the form of force interaction from the obstacle itself.

In the second considered case, where the virtual influence zone is related to the mobile robot, the operator will receive information about approaching the boundary of the manipulator's workspace and objects without their own influence zones.

The external layer assumed in the accepted model is the audiovisual information layer. When the robot enters the area of this layer, the operator is informed by the appropriate sound and text message displayed on screen or on a different control device. When moving within this zone, the operator does not receive force feedback (does not physically feel the influence of this layer on the joystick). This layer performs the role of early warning against contact (potential collision).

In contact with the middle layer, information about the contact with it is transmitted in the form of force acting on the joystick, forcing the system's operator to, for example, to change the robot's movement speed or make the necessary correction to its motion trajectory. The system's operator physically senses that the robot is in close proximity to an obstacle and is forced to react accordingly. The robot brakes automatically, so that no sudden impact with the obstacle occurs. The application of this layer in control of mobile robots will make it possible to reduce the robot's movement speed and brake automatically in front of an obstacle that appears. This is an important factor, particularly with regard to the case where the robot's weight is significant (e.g., mobile robot supplying and gathering feed for animals), because such a robot will have high inertia. When travelling at a small distance from an obstacle, the mobile robot will slow down automatically, thus providing the operator with additional reaction time (e.g., for precise bypassing of the obstacle). However, this layer does not affect the robot's direction of travel. After leaving this layer, the robot will automatically increase its movement speed to the previously input value.

The inner layer found closest to the object (obstacle) affects the robot's direction of travel, not allowing it to approach to a distance that may result in physical contact with the obstacle. It serves as an invisible barrier from which the robot "bounces off". Depending on the needs, such "bounce-off" may cause a mild change in the direction of movement or cause the robot to come to a full stop. Therefore, this layer does not only affect the robot's movement speed (positioning of its effector) but also changes the direction of input motion (position of end effector).

In the accepted control model, two types of virtual influence zones are distinguished: 1) static zones and 2) dynamic zones.

Static zones do not change their geometrical parameters or position relative to an obstacle. Meanwhile, dynamic zones can change both their position relative to an object and their size depending on the direction of travel of a given obstacle identified by the robot's sensor system. This is a significant assumption, particularly when we are dealing with obstacles moving in a specific direction (Fig. 3).

Fig. 3. **Moving obstacle with dynamically changing virtual influence zone**

In addition, the size of the entire zone or of one of its layers may be made dependent on the velocity (or acceleration) vector of the moving obstacle (Fig. 3). Obstacles moving more quickly will have larger zones of influence, so that the robot is capable of braking in time and preventing a potential collision.

A static zone of influence is described by constant parameters. Its shape and size are accepted from the very beginning and do not change during work (Fig. 4). Information transmitted by virtual zones of this type is constant, regardless of the depth to which the mobile robot penetrates.

Fig. 4. **Static zone of influence related to stationary object**

A dynamic zone of influence can also be assigned to a robot that does not travel, but changes its geometrical parameters during work (e.g., milking robot or automated milking machine). Such machines are characterized by a specific workspace in which the robot's end effector moves. It does not occupy the entire space at any given time, but its position may change dynamically.

The position and size of the virtual zone of influence should, in principle, adapt to the current position of the manipulator's end effector. The external layer should correspond to the manipulator's workspace and may be static. Meanwhile, the middle and inner layers must be dynamic and track the position of the end effector.

Results and discussion

1. Implementation and testing of the described control method for mobile robots was performed using the Rovio commercial mobile robot from WowWee [19]. This robot is equipped with a system registering its position relative to the base, and it has a video system consisting of one camera transmitting video to the control computer.
2. Virtual influence zones combined with haptic device systems constitute a part of a larger control system for mobile service robots that is being developed by the authors of this paper, dedicated for work in sheds used for animal breeding. A 3D virtual work environment of mobile robots built on the basis of actual surroundings (cowshed interior) constitutes the basis of this system. The system is being developed in the Visual Studio environment with the use of C++ language syntax and DirectX libraries [20; 21]. Information about this environment is available for all mobile robots moving within it. Access to this information is implemented via a Wi-Fi network. Every robot transmits locally gathered information to the computer system and also gains a global picture of the entire environment thanks to data exchange (transmission). Thus, every robot is informed in an ongoing fashion about changes occurring at other locations in the cowshed, allowing for more precise planning of its motion trajectory.

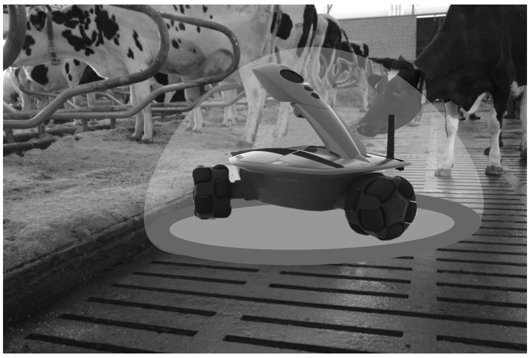

Fig. 5. **Combining image from mobile robot's camera with computer-generated image**

3. At the current stage of the research, the environment (surroundings) in which the robot moves only contains defined stationary obstacles. The robot detects and identifies obstacles thanks to markers placed on given obstacles. The robot sends information about the dimensions, position and orientation of obstacles in three-dimensional space to the system, in which a virtual map of the surroundings is built [22]. The system assigns the appropriate static zones of influence to obstacles. Information about the created virtual map of the surroundings will be available for other robots moving and operating within the environment.
4. A camera image transmitted by the Rovio mobile robot with a superimposed image of the virtual zone of influence is presented in Fig. 5. It shows two layers of the virtual zone of influence, i.e. the audiovisual information layer and robot movement parameter change layer. When the robot is found in the informational layer, a sound signal is generated. When it enters into the inner layer, its speed is reduced to half of its initial, input value. After the robot leaves the zone, its speed is increased to the value corresponding to the one originally input on the given segment of the trajectory.

Conclusions

1. Virtual zones of influence combined with haptic devices and mobile robots will allow for better control of robots and will also make teleoperation processes more efficient. Pathfinding algorithms for robots may account for the position of virtual zones of influence and their effect on the robot's speed. This, in turn, will make it possible to determine optimal motion trajectories for mobile robots and may contribute to the development of new control methods for other mobile robots, e.g. unmanned aerial vehicle (UAV) swarms.
2. In work on the automated system planned in the future, a module will be built to enable the operator of a robot equipped with a video system to see the image transmitted by it along with superimposed virtual zones of influence. Combining the real image with an image generated by the system is possible thanks to the application of the augmented reality technique. This technique

changes the 2D image from the robot's camera into a 3D image by using markers placed on obstacles. Thanks to this, it is possible to identify marker positions in space, and thus, the positions of the obstacles associated with them. Next, a computer-generated image of the virtual zone of influence is imposed in the place of the markers. Seeing a zone generated in this manner on the control computer's screen along with an image of the mobile robot's surroundings, the operator will know what reactions can be expected of the robot.

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