LiSA: A Robot Assistant for Life Sciences

Erik Schulenburg[1], Norbert Elkmann[1], Markus Fritzsche[1], Angelika Girstl[2],
Stefan Stiene[3], and Christian Teutsch[1]

[1] Fraunhofer Institute for Factory Operation and Automation, Sandtorstrasse 22,
39106 Magdeburg, Germany,
`<firstname>.<lastname>@iff.fraunhofer.de`
[2] Sympalog Voice Solutions, Karl-Zucker-Strasse 10, 91052 Erlangen, Germany,
`girstl@sympalog.de`
[3] University of Osnabrück, Albrechtstrasse 28, 49069 Osnabrück, Germany,
`sstiene@informatik.uni-osnabrueck.de`

Abstract. This paper presents a mobile service robot that assists users in biological and pharmaceutical laboratories by carrying out routine jobs such as filling and transportation of microplates. Relevant requirements are outlined and an overview of the design of the mobile platform with a robotic arm is provided. Moreover, the approaches to object recognition and intuitive multimodal human-machine interaction using speech and touchpad input are described. The main focus of the project is aspects of safety since the robot and humans share a common environment and actually cooperate. Hence, a safety concept has been devised, which consists of various sensor systems such as laser scanners, thermographic components and artificial skin.

Key words: service robotics, mobile robot, object recognition, human-machine interaction

1 Motivation

Much progress has been made in the field of service robotics in recent years. Yet, autonomous robots have still not entered everyday life because the scenarios propagated in literature and science remain impracticable at present. Robots performing domestic work will have to accomplish many complex tasks, each of which is subject to intense research work. Key aspects are:

- Localization and navigation in highly dynamic environments,
- Reliable object recognition and manipulation and
- Natural human-robot interaction.

Moreover, projects that endeavor to integrate these aspects in a single system often fail to incorporate safety requirements.

The LiSA project is focused on integrating the latest research findings in a feasible service robot that meets the high level of safety demanded in real world human-robot collaboration. Figure 1(a) is a design study of the particular robot currently under development.

Previous service robotics projects such as the MORPHA project [1] have primarily centered on fields of industrial manufacturing or domestic work. The manufacturing environment is highly structured. Human workers in this domain are familiar with machine operation and pertinent precautions. Manufacturing and domestic settings are extremely different in this regard. A household environment is extremely dynamic. A robot operating in and interacting with this environment has to deal with various objects. At the same time, it may neither cause any damage nor harm people, even if they are careless. This makes the domestic settings impractical for service robots at present. The approach presented here is for the domain of life sciences. Life science laboratories have semi-structured environments. Objects like bottles and microplates are standardized and access can easily be restricted to those who have learned to interact safely with the robot. Nonetheless, this scenario constitutes a meaningful application for using a robot, since many tasks in life sciences are monotonous, hazardous or highly sterile.

2 Related Work

Numerous projects in recent years have aimed at developing service robots. Despite all the research done, only a few systems have become commercially available, e.g. the HelpMate robot [2] used for drug delivery in hospitals. Most systems are individual robots employed for special purposes like guiding visitors through museums [3]. Other projects have focused on user friendly interaction with robots. In general, these use natural language to communicate intuitively. Examples of such systems are the office assistant Jijo-2 [4] or the robot companion BIRON [5]. These robots have integrated spoken dialog systems but are unable to manipulate their environments. The key idea behind the research initiative MORPHA [1] was to develop service robots with capabilities to assist human users in manufacturing and health care. This project produced the robot assistants rob@work [6] and Care-O-Bot [7]. Research involved studying the interaction, collaboration and communication with human users through natural language and gestures. Safety aspects were not broadly considered though. Another application for a scenario similar to that of the LiSA project is the mobile


(a) (b)

Fig. 1. Design studies of the LiSA platform (a) and the robotic arm (b).

robot for automated cell cultivation developed at the University of Bielefeld [8]. A mobile robot with a manipulator takes and manages samples in a biotechnological laboratory. The project only marginally examined safety requirements and interaction with the robot.

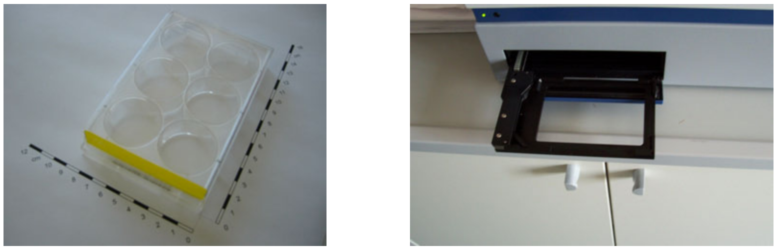
3 Project Overview

Biological and pharmaceutical research entails a great deal of repetitive manual work, including the preparation of experiments or the loading of equipment such as drying chambers and centrifuges. Classical automation uses band conveyors or indexing tables to interconnect such units [9]. This approach has two drawbacks though. It is inflexibile and the stations do not lend themselves to use for variable experiments performed by human workers. The basic idea behind the Life Science Assistant (LiSA) is to employ a mobile service robot to interconnect equipment. Flexible automated experiment cycles are obtained, while stations can be simultaneously used for other purposes. In addition, the robot helps employees prepare experiments, e.g. by collaboratively executing transportation tasks or filling microplates. Figure 2 presents typical objects the LiSA robot has to deal with in this scenario.

3.1 Project Objectives

Partially funded by the German Federal Ministry of Education and Research (BMBF) the LiSA project is constructing a demonstrator that completes the tasks described above. The specific objectives of the project are:

- Development of a mobile platform capable of navigating a laboratory with narrow corridors and doors. The platform has to meet high safety standards to receive official approval.
- Platform navigation in the dynamic environment of the laboratory. The robot has to detect nearby people and other objects early enough to avoid collisions and prevent injuries and damage.



(a) (b)

Fig. 2. Typical objects used in a laboratory environment: microplate (a) and a drawer in lab equipment (b).

- Development of a manipulator for handling relevant objects and interacting with human beings. The robot arm and gripper also have to meet high safety standards. Therefore, miscellaneous sensor systems are being designed to ensure as much safety as possible.
- Visual recognition and localization of objects and shelves. Stereo vision determines the position and spatial orientation of the microplates. Therefore, a stereoscopic camera system is employed. This system allows 2-D real-time position tracking and the computation of 3-D samples from the object surface to exactly guide the manipulation system.
- Multimodal human-machine interaction. If users are to accept it, commands given to the robot assistant have to be as intuitive as possible. LiSA is equipped with a touchscreen combined with a spoken dialog system. These two modalities can be used interchangeably and input in one modality can be augmented with input in the other.
- Integration of the aforementioned components in a working demonstrator.

The main priority of each of these objectives is safety, i.e. the robot may not harm any people or damage its environment. Even though safety is a prerequisite to official approval for the mass market, most other projects have disregarded this important aspect. Safety takes on even greater importance in the life sciences because the robot may deal with toxic or hazardous substances.

3.2 Use Case: Transportation Task

The sequence of a typical transportation task completed with the assistance of the LiSA robot is outlined below. The user commands LiSA to take a sample from the preparation table and measure its fluorescence. The user additionally directs LiSA to place the sample in the drying chamber afterward.

1. The user gives LiSA the command in natural language.
2. LiSA approaches the table.
3. LiSA takes the microplate from the exchange area.
4. LiSA navigates to the fluorescence reader.
5. LiSA places the microplate in the drawer of the fluorescence reader.
6. The fluorescence is measured. (LiSA may complete other jobs at this point.)
7. LiSA removes the sample from the fluorescence reader.
8. LiSA navigates to the drying chamber.
9. LiSA places the sample in the transfer lid of the drying chamber.
10. LiSA notifies the user that the task has been completed.

This scenario has been simplified for purposes of illustration and presents just one possible use case. In reality, several interlocked tasks may be executed simultaneously. However, the model sequence highlights the different challenges faced. The mobile platform and navigation required in steps 2, 4 and 8 are described in this paper in sections 4 and 5, the robotic arm and the computer vision approach applied in steps 3, 5, 7 and 9 in sections 6 and 7 and interaction with the robot in steps 1 and 10 in section 8.

4 Mobile Platform

The mobile platform is equipped with two independently steered wheels resting on inclined edges. To prevent the platform from buckling laterally, two additional castor wheels rest inside the remaining edges. One of these castor wheels is cushioned to ensure all wheels constantly remain in contact with the ground even when it is bumpy. This wheel configuration furnishes the mobile platform with advanced navigation capabilities , i.e. the platform is able to turn in place and move laterally. These are fundamental features ensuring the high maneuverability needed to navigate in tight environments such as in laboratories.

The platform is able to travel at speeds up to 0.8 m/s. For navigation the platform is equipped with a gyroscope, wheel encoders on the driving wheels and six 2-D laser scanners. The gyroscope and wheel encoders track the platform's current orientation and movement. The laser scanners provide data for navigation and obstacle detection. For safety applications these laser scanners provide an alert area and a protection area. The safety system is completed by bumpers mounted all around the bottom edges of the mobile platform. If an obstacle violates the alert field of a laser scanner, the mobile platform slows down. Just as pressing one of the emergency stop buttons, activation of the protection area or of any other safety sensor element will result in an immediate stop. The domain of the mobile platform will not be bordered by any hardware arrangements. Navigation and orientation are executed autonomously. This claim results in extremely high safety requirements to protect men and environment from damage by the mobile platform.

5 Localization and Navigation

The LiSA project does not include the autonomous exploration of the environment. In fact a prior navigation map of the environment is built for path planning and localization. Therefore, the environment is scanned in all three dimensions using the mobile robot Kurt3D [10]. This robot is equipped with a 3-D laser scanner enabling it to obtain a three dimensional point cloud of the environment (see Figure 3). This is achieved by iteratively taking 3-D scans and registering these scans to a consistent point cloud using a 6-D SLAM algorithm based on "iterative closest points". The point cloud is semi-automatically converted into a map for the USARSim robot simulation environment (Figure 5(a)). The simulated environment is used to build a 2-D map for navigation (as a 2-D slice of the simulation refined manually) and is additionally integrated in the graphical user interface.

For localization the LiSA robot employs a new sensor configuration that enables it to navigate with full 3-D obstacle avoidance, produced by combining 6 laser scanners to a robot centered 360° full 3-D laser scanner. Two laser scanners (SICK s300) are mounted on opposite corners of the robot. The scanners' 270° field of view generate a 360° field of permanent 2-D view even with overlapping regions (See Figure 4(a).) This combined 360° scanner serves two purposes: (1)

in conjunction with odometry, it is used for localization in a prior map (and is therefore called "localization scanner" below); (2) it acts as the safety sensor necessary on the holonomic platform for constant avoidance of collisions with humans. It is insufficient for general obstacle avoidance, since obstacles may interfere with the robot in its complete bounding box. To obtain 3-D obstacle avoidance, the setup is extended by four Hokuyo URG-04LX laser scanners each of which is mounted at the bottom of one of the robot and angled upward, enabling the robot to detect obstacles in the respective data. If this is the case the 3-D laser data point (belonging to the obstacle) is projected to the floor plane (see Figure 4(b)) and inserted into a local perception map. Hence, the robot must move to generate a detailed perception map. The 360° "obstacle avoidance scanner" combines the localization scanner with the perception map regarding the current robot position. The complete system has been tested in the robot simulation environment USARSim [11]. Figure 5(a) pictures the LiSA platform in USARSim. The simulation environment is connected to the hardware abstraction layer of Player/Stage [12]. Figure 5(b) shows the standard player sensor data visualization tool. The obstacle avoidance scanner (blue data) and the map generated by the Hokuyo scanners are shown for the situation in Figure 5(a). The obstacle avoidance scanner is aware of the whole environment. Figure 5(c) depicts the localization scanner which is only able to detect the chair and table legs and the far walls.

6 Manipulating the Environment

A robotic arm that manipulates, grips and transports is centrally mounted atop and towards the rear of the mobile platform. Thus, the arm is able to operate to the left or right of the mobile platform. The initial goals for robotic arm development included not only the desired functionality but also simple construction to easily integrate and evaluate sensor/actor elements for collision avoidance. Based on these requirements, a classical SCARA arm design was selected. The robotic arm consists of three joints with three vertical rotation axes and one linear axis

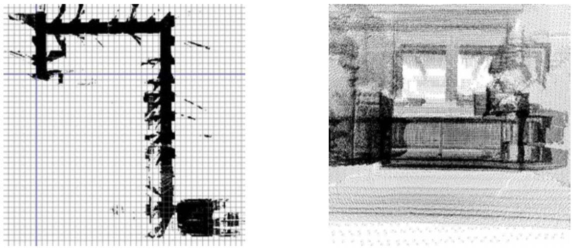

(a) (b)

Fig. 3. Overhead view of the scanned point cloud (a). Perspective view of part of the point cloud (b).

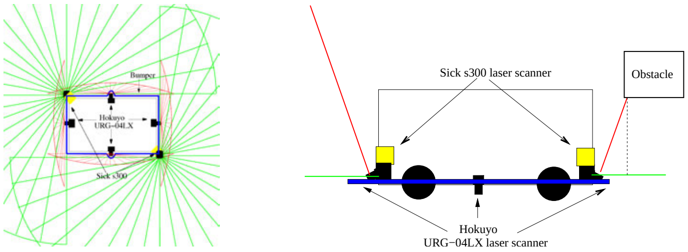
at the front of the manipulator. The linear axis supports a 2-finger gripper (see Figure 1(b)).

The manipulator is covered by a pressure-sensitive artificial skin for collision detection. The skin's design enables localizing the collision area. The chosen design gives the manipulator clearly defined directions of movement (horizontal for the joints, horizontal and vertical for the linear axis). Therefore, tactile sensor elements only have to cover specific areas. Torque measurement and contouring error control are integrated in the joints as additional electronic safety functions. As the final link in the safety chain, the manipulator is padded to prevent injuries in the case of a collision. The manipulator stops immediately whenever one of its collision detection systems has been activated. The first collision detection system is the artificial skin. The padding absorbs impact energy. The safety functions actually implemented represent the first step towards meeting the requirements of EN ISO 13849 (Safety of machinery). Further safety functions will be implemented if a risk analysis based on DIN EN 1050 indicates they are needed.

The robotic arm is equipped with two camera systems for camera-guided movement. A stereo camera system is installed near the linear axis, while a combined camera system (see section 7.3) is mounted at the base of the robot arm as can be seen in Figure 1(b). The combined camera may be rotated independently from the robotic arm but should always be trained on the gripper.

7 Optical Sensor Technology

The following presents basic approaches to automated guidance of the robotic arm and its gripper as well as additional functionality to support the safety elements. In particular, the approaches to object recognition and the determination of human interaction are examined.



(a) (b)

Fig. 4. Overhead view of the LiSA robot's laser sensor configuration: Two SICK s300 scanners (green laser beams) and four Hokuyo laser scanners (red laser beams).

7.1 Object Recognition

Optical sensors identify and recognize the exchange positions and the microplates. To reliably position the gripper vis-à-vis objects being picked up, two digital cameras sample the immediate environment. The cameras' color depth of 8 bits and resolution of 1032×778 pixels represent a compromise between computation time required for image processing and the accuracy of the result required. The lenses employed enable capturing an area of about 400×300 mm. By using subpixel interpolations, a resolution of ca. 9 pixels/mm^2 is produces, which is sufficient for determining the necessary positions.

The detection of the microplates at the exchange positions is based on a fast and adaptive segmentation approach. In a first step, a histogram is computed. As proposed by Rosin [13], the histogram value at the half between the minimum and the maximum is taken as the binarization threshold. The segmented result represents the area of the microplates. In the subsequent steps, the border is calculated in an 8-neighborhood. The rotating calipers method is used to obtain the smallest bounding rectangle from the extracted contour. The orientation of this rectangle defines the orientation of the microplate and thus the required orientation of the robotic arm and its gripper. A black foam was found to optimally eliminate artifacts from reflections and uneven lighting.

Furthermore, the exchange positions are labeled with coded markers (see Figure 6(b)). This enables comparing the robot's actual position with the expected one and utilizing further algorithms to compensate for uncertainties from the global navigation.

Since the microplates are transported from the exchange position to analysis instruments with their own object interfaces, another algorithmic approach must be employed. Therefore, the entire workspace and the instruments have been modeled beforehand in CAD space. The model information from the actual surrounding CAD space is utilized to generate virtual, synthetic images of the scene observed in front of the sensors. This is done by determining the camera's position and orientation relative to the object being considered. The original image is compared with the synthetic image that depicts the expected.

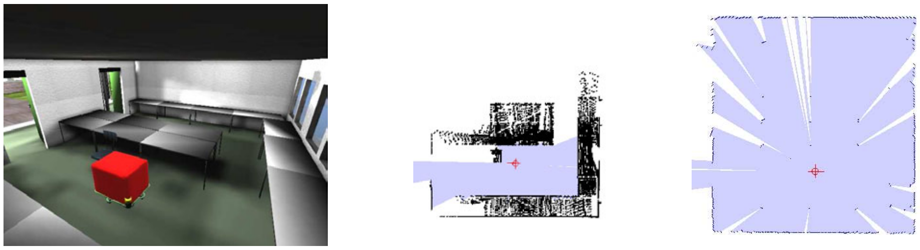

(a) (b) (c)

Fig. 5. The LiSA platform in the USARSim simulation environment (a), obstacle avoidance scanner and local perception map (b), localization scanner (c).

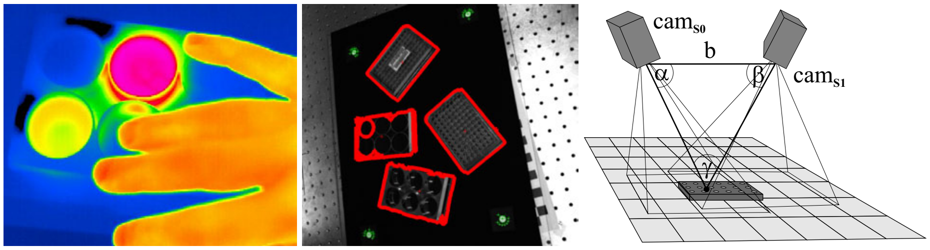
The information derived serves as the basis for calculating and subsequently refining regions of interest for unknown interface locations.

7.2 3-D Feature Detection

The determination of exact 3-D position and orientation is based on a photogrammetric approach. Therefore, both digital cameras are used. Their positions and orientations are predetermined in a prior calibration step [14]. The triangulation principle serves as the basis for calculating the relative 3-D coordinates of objects visible to both cameras (see Figure 6(c)). Corresponding pixel pairs are identified by using statistical correlation between image segments on the epipolar lines [15]. The small base distance b of 150 mm necessitates aligning the camera's perspective to attain sufficiently high precision (< 0.5 mm) in the stereo-vision approach based on triangulation. When the robotic arm moves, the algorithms track the 2-D position of microplates on the one hand and take 3-D samples of the object's surface on the other hand. The resulting height data supports algorithms to detect plates on the top of one another.

7.3 Thermography

A thermographic component is employed to ensure the safety of the manipulation process. This infrared component is part of a third combined camera device. Basically, it consists of two cameras, one for the infrared and one for the visible spectrum. The integrated cameras are calibrated to enable this system to merge visible and infrared images. The resulting four dimensional information (p_x, p_y, I, T) is utilized to detect human interaction in front of the robotic arm and its gripper (see Figure 6(a)). The camera is mounted on a rotating stage and moves adaptively as the robotic arm moves.



(a) (b) (c)

Fig. 6. Components of LiSA's optical system. A thermographic component for easily detecting human interaction (a), a camera component for 2-D position tracking (b) and a stereoscopic sensor for taking 3-D samples (c).

8 Interaction through Speech

LiSA is designed to receive instructions directly from laboratory assistants. Their interaction with LiSA has to be intuitive, fast and easy. Interaction with LiSA is multimodal, i.e. spoken and touchpad input are possible. Speech recognition is speaker-independent. The commercial dialog engine used for LiSA supports mixed-initiative, natural language dialogs and conversation in full sentences. It has been expanded for multimodal input for the LiSA projects, experiences with which are available from the SmartWeb [16] and SmartKom [17, 18] projects.

The dialog engine extracts all pieces of information from a spoken utterance and touchpad input. To send a command or a request to the robot's Task Manager, information has to be entered into a predefined XML form. The dialog engine asks for missing pieces of information and sends the completed form to the LiSA Task Manager. Several such XML forms are defined for several tasks, e.g. transportation orders, orders to complete a measurement, requests for information about a task's status or requests for information about the robot's status.

Orders and requests for information can be placed by spoken dialog with the robot or by touchpad input. LiSA can have two independent users, each with a touchpad for graphic input and a bluetooth headset for spoken input. The touchpad and the headset communicate with the robot by WLAN. Both modalities, spoken and graphic interaction are closely connected, i.e. touchpad input influences spoken dialog and vice versa. The system always replies on both channels simultaneously. Speech output, requesting the location of an object for example, is combined with a laboratory map or a list of possible locations displayed on the touchpad. Spoken commands and touchpad input can be used in combination or independently throughout the dialog. This includes combinations of touchpad input and speech signals in a single utterance, e.g. the sentence "take the sample from this point to that point" is combined with two touchpad input events on the map displayed. However, users may also use only one modality, speech or touchpad, if they prefer. The following dialog illustrates this possibility:

System: What can I do for you? [display: status]
User: Take the sample to the drying chamber in room 112.
System: Where is the sample located? [display: map]
User: At the pipetting station here. [touching a room on the map]
System: Order will be executed. [display: list of orders]

Graphic output is produced by sending information about the ongoing dialog to a GUI engine. Based on this data, the GUI decides how to structure the display and what content to display. The dialog engine also interacts with a knowledge database that stores information about the location of laboratory inventory such as the fluorescence reader, pipetting station or drying chambers and their location in the different rooms of the lab. The robot's computer also has an open channel to retrieve information about the robot's status and to place orders. The robot's computer itself can send messages to notify users when problems and errors occur or when taks are completed. Error messages interrupt any ongoing dialog. Once a problem has been remedied, the interrupted dialog can be continued. The features described generate mixed-initiative, multimodal interaction between laboratory assistants and LiSA. Intuitive interaction is the foundation for efficient human-robot cooperation in the laboratory.

9 Conclusion and Further Work

This paper presented an overview of the LiSA project aimed at developing a feasible service robot for laboratory automation. The requirements were laid out, emphasizing the importance of safety standards necessary for a service robot to operate safely in an environment shared with humans. The design of the mobile platform and the robotic arm incorporate these requirements in the various safety sensors such as the laser scanners, bumpers, thermographic components and artificial skin, which are designed for maximum safety.

The approaches to object recognition and multimodal interaction were also elucidated. Object recognition relies on stereo vision to determine the exact 3-D position of objects. This information is used to guide the robotic arm to its gripping position. Multimodal interaction incorporates spoken and touchpad input. These two modalities can be used interchangeably or even conjointly.

Further steps in LiSA project work will involve refining and implementing the concepts described here. All aspects of the development work will converge in the construction and testing of the final service robot by March 2009.

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