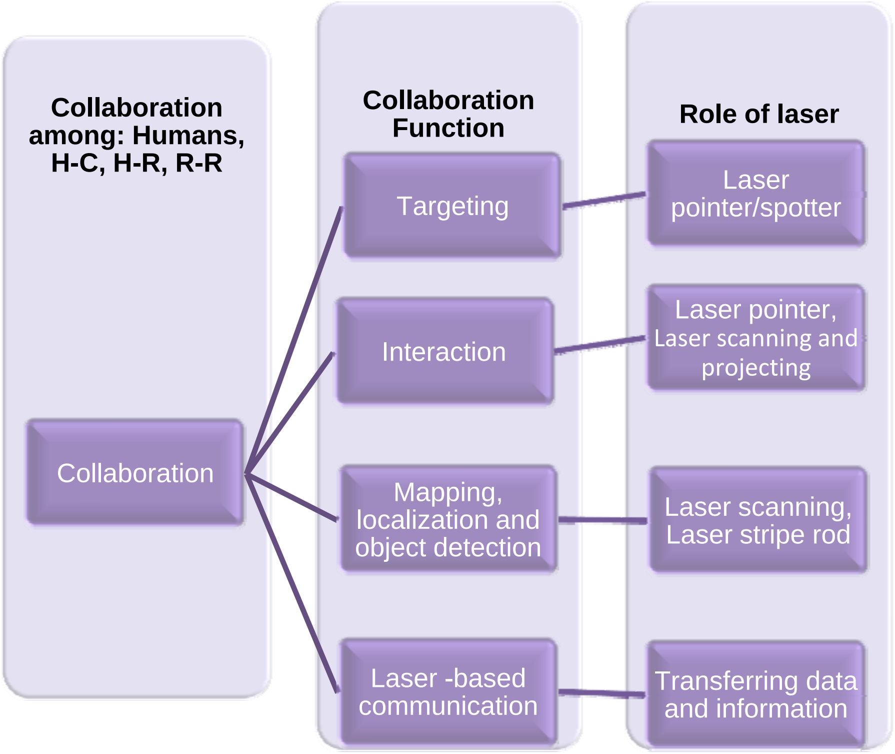
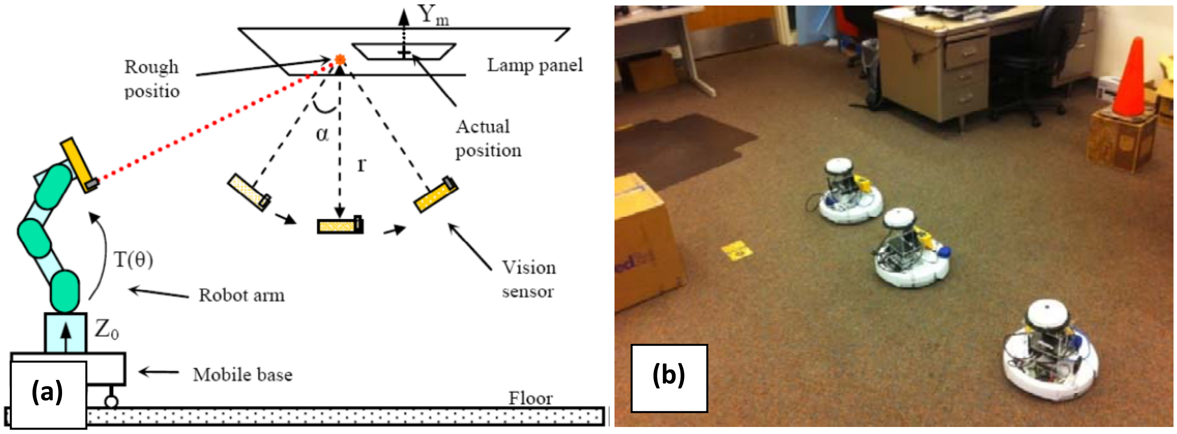


Figure 3. Precision Collaboration Framework: Emerging laser roles in precision collaboration (H- Human; C- Computer; R- Robot).



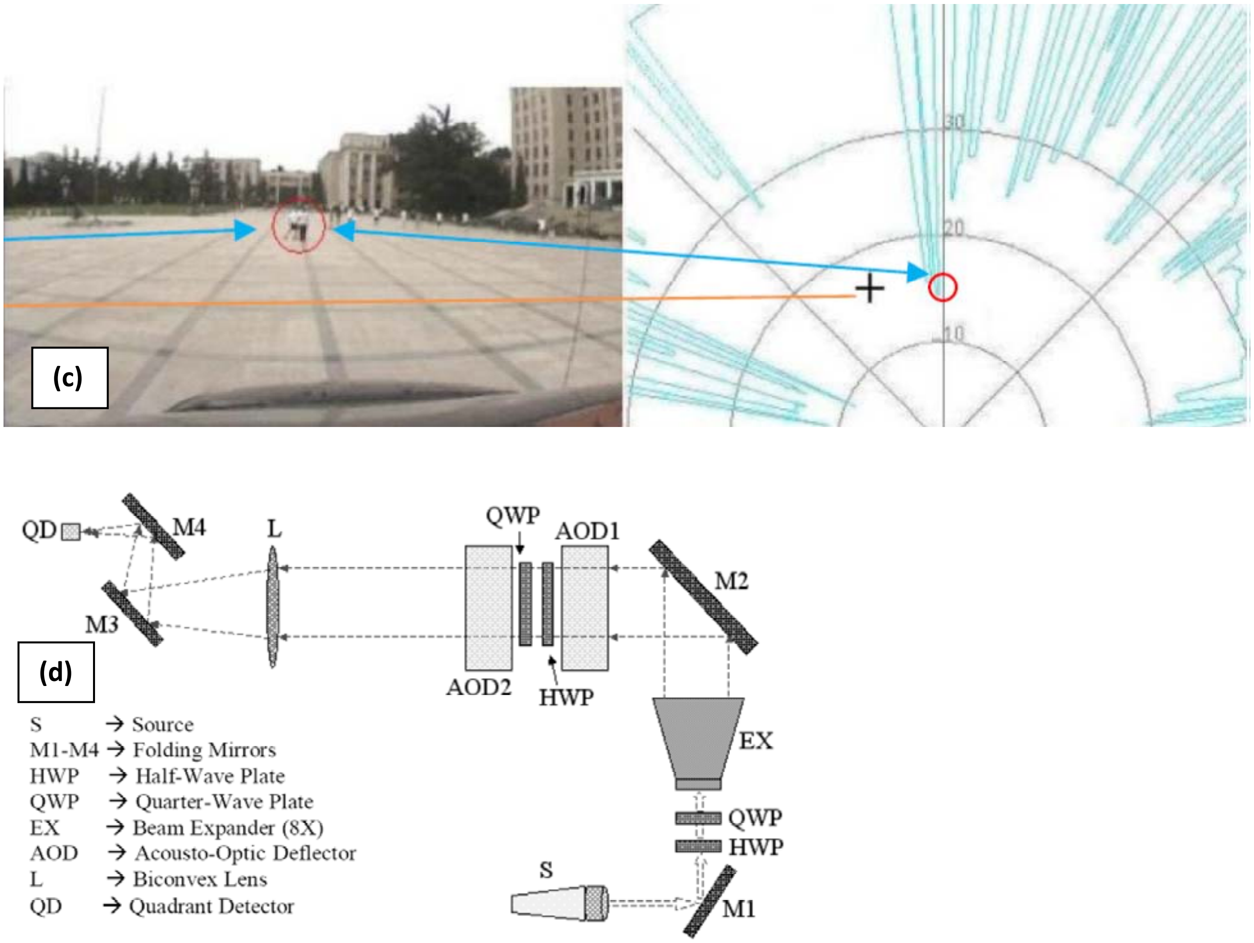


Figure 4. Illustration of precision collaboration functions. a) targeting (Cruz-Ramirez et al. 2008); b) interaction (Li et al. 2011); c) mapping, localization and object detection (Wenjian et al. 2009); and d) laser-based communication (Nikulin et al. 2006).

4.1 Precision Collaboration Function 1: Targeting

Targeting implies the precise identification of an object and its exact location. For example, defining the position and orientation of a pepper to be harvested by a robotic device. A laser pointer provides a powerful alternative as a user interface for robot control. It is cheap, lightweight, points accurately, and is reliably recognized (Ishii *et al.* 2009). Previous research showed that a laser pointer can be useful for providing target designation for a picking-up robot

(Kemp *et al.* 2008) and developed a button-pushing robot (Suzuki *et al.* 2005). A wearable interface for remote collaboration through pointing, enabling remote human collaborators was developed (Kurata *et al.* 2004, Figure 5). A body-worn steerable laser pointer and a fixed camera to enable remote collaboration was used (Mann 2000) and applied for hands-free telepointing with completely self-contained, wearable visual augmented reality.

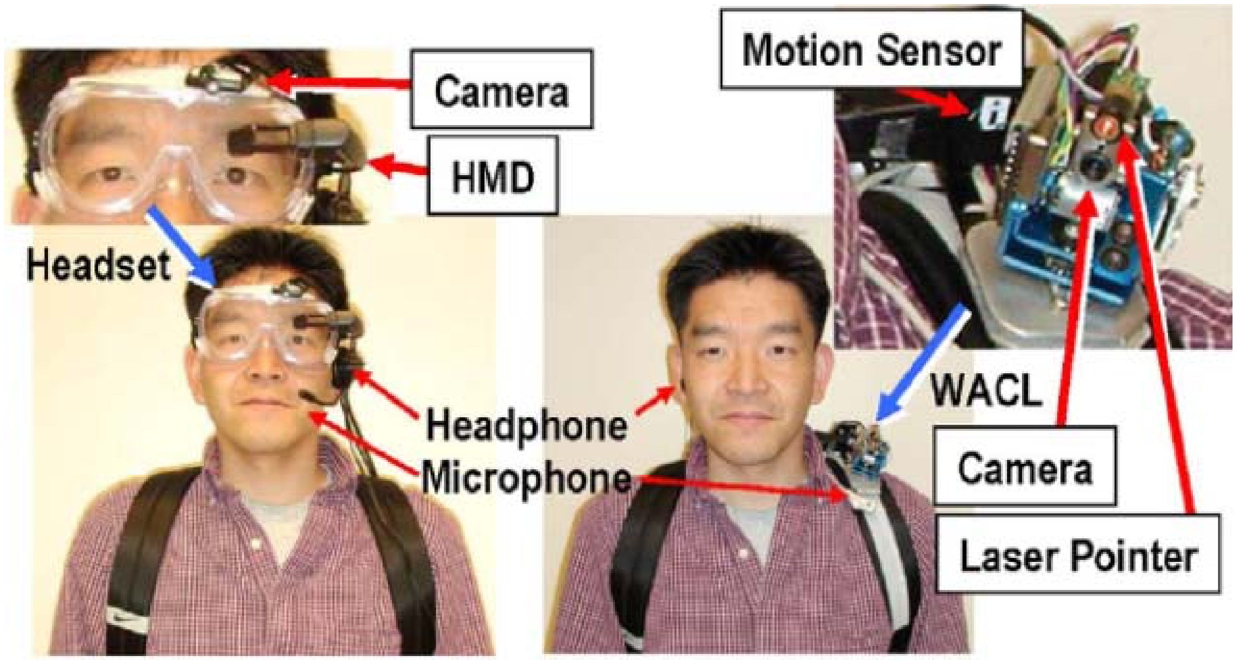


Figure 5. A wearable interface for remote collaboration with the ability to point to real objects in the task space with a laser spotter (Kurata et al. 2004).

An adaptive sensor fusion-based object tracking and human action recognition was developed (Yeong Nam et al. 2009) for interactive virtual environments. This system tracks robustly people in virtual environment and can recognize their actions. It is view invariant, and uses an adaptive sensor fusion approach to couple between the laser scanner and a video camera. In this system, a person can interact with virtual agents simultaneously in an interactive virtual environment. Cruz–Ramírez et al. investigated the use of lasers for targeting ceiling objects, such as light panels, to dismantle building’s interior facilities, using a human-robot collaboration

(Cruz-Ramirez et al. 2008) platform. A laser pointer fixed at the robot's tip served both as a guide during the teleoperated task, and as the first indicator of the current holding position. Work piece positioning and objects mapping for industrial robots tasks were performed by projecting laser spots over the workpiece, which later allowed gathering information about the workpiece geometry with a multi-camera system (Gonzalez-Galvan et al. 2003). Young Sang et al. developed a mobile robotic manipulator that can grasps objects previously marked with a laser pointer by a human operator (Young Sang et al. 2008). In this task, the grasping was done autonomously by the robot.

A human robot interaction (HRI) system for robot tool path planning in augmented reality environment was developed and tested on a laser welding industrial robot (Li et al. 2007, Chuen Leong et al. 2010). The HRI system used information from both a camera and a laser range finder. This system detected and tracked a laser spot projected by the laser range finder. As indicated earlier, Glossop et al. combined laser with augmented reality for projecting surgical plans, entry points for probes directly onto patients (Glossop et al. 2003).

In the above targeting examples, precision is of paramount importance for cost-effective and high quality tasks completion. Furthermore, precise and error free data acquisition transmission is required to assure adequate levels of safe interaction between the collaborating parties (e.g. humans, robots, machines and devices).

4.2 Precision Collaboration Function 2: Interactions

In the past, laser pointers were mainly used for target labelling in the field of robotics, while exploring their potential as versatile input devices was not deemed neccesary. As indicated by Ishii et al., target designation on its own is far from sufficient for a human-robot interface (Ishii *et al.* 2009). Ishii et al., suggested that laser pointers can be effective also for specifying commands and target locations for a robot to follow. In that work, laser pointer-based user interface was used for issuing instructions to a robot. Stroke gestures over the laser's trajectory served as the main modality to deliver instructions. Through this interface, the operator could draw gestures using a laser pointer to specify target objects for the robot to execute.

A different paper suggests using laser pointer as a robot-controlling interface. Such a laser gesture interface was designed and implemented to issue instructions to a mobile robot. More specifically, Oh and Stuerzlinger describe a system that uses computer controlled laser pointers as interaction devices for displays control. The paper discusses a number of alternatives for distinguishing between different laser pointers' arcs (Oh and Stuerzlinger 2002). The input devices adopted can provide concurrent input streams to a single display groupware environment and applications. A framework that supports multiple pointing devices to explore collaboration and interaction in graphical environments has also been developed (Vogt et al. 2004).

Tracking fingers has been introduced for gesture recognition in human-computer interfaces (Perrin et al. 2004, Cassinelli et al. 2005) through the use of lasers. Active tracking has been implemented through using a laser diode (with invisible or visible light), steering mirrors, and a photo-detector. Successful tracking has been achieved through the analysis of the backscattered light, measured by the photoreceptor during a millisecond-long circular laser saccade around the position of the target. This procedure has enabled the acquisition of real-time, three dimensional coordinates in a relatively narrow window (concerning the target size). By implementing such a sterile finger tracker, this procedure can be applied to extend current efforts in the area of interactive medical imaging for healthcare operations (Wachs et al. 2007, Wachs et al. 2008, Jacob et al. 2012a, Jacob et al. 2012b).

In the previously illustrated cases, benefits of using laser technology include operational cost-effectiveness, quality based on the precision of communicated information, and reduction in total process time. Avoiding errors due to imprecise control can lead to safer procedures (e.g., medical applications) and fewer commands.

4.3 Precision Collaboration Function 3: Mapping, localization and object detection

Mapping, localization and object detection can be essential for sustaining proper levels of collaboration. In such contexts, the devices commonly used to support the collaboration were laser range scanners and were not part of the collaboration itself, but merely a tool enabling decisions. Harb et al. described the role played by a mobile robot in a clean-room medical facility. In this system, the integration of collaboration techniques was necessary for successful completion and effective performance of given complex missions (Harb et al. 2009) . Collaboration was achieved by mapping data extracted from a laser range scanner, which used as the sensed signal in several control systems within the robot.

In other cases, where cooperative localization or mapping was the objective, the goal was accomplished by interactive communication between mobile robots and a network of laser range scanners (Morioka et al. 2012). Zhuang et al. studied the problem of cooperative localization based on environmental information in an unknown, complex environment. They developed an algorithm for adaptive selection of multi-robot cooperative localization using an extended Kalman filter in the cluttered environment (Zhuang et al. 2010). Li et al. (2011) developed a network surveillance system based on data fusion algorithms for collaborative target localization.

Laser scanning was used in a number of mapping applications, e.g., for (1) mapping and localization of the robots' relative positions for a team collaborating in a search and rescue

(Guarnieri et al. 2009); (2) mapping and obstacle detection in a collaborative autonomous unmanned vehicles navigation (Ying et al. 2009); and (3) force feedback enhanced teleoperation for outdoor robotic vehicles navigation (Jarvis 2010). Collaborative mapping was developed for a team of robots where each was equipped with its own laser range finder (Rogers et al. 2011). In this application, a distributed data fusion algorithm was used to combine the local maps produced by each robot into a shared global map. Multi robot collaborative localization using data fusion from laser scanners was investigated in number of studies (Jiang and Chen 2008, Tseng and Tang 2009).

In telerobotics, environment mapping has is key to the success of the human/human and human/robot interaction and the operators' situation awareness. The use of actionable knowledge extracted from a 3D map produced by a laser range scanner was shown to improve teleoperation. Livatino et al. conducted an experiment to examine the value of a graphical elements used in telerobotic system, where a robot is manipulated by an operator located remotely (3,000 kilometers away). The results validated the simplicity and effectiveness of the experimental approach proposed (Livatino et al. 2010) .

Several HRI (human-robot interaction) based systems applied laser range scanners to detect people, identify faces and gestures. For instance, Marcos et al. used a laser scanning technique to create virtual head orientations for human-computer interaction with social robots. Interpretation of human attitudes was achieved by detecting and tracking indoors human movements by using a PTZ camera and a laser range finder (LRF) mounted on a mobile robot (Marcos et al. 2010). After detection of humans, gait was analyzed in search of meaningful patterns (Ramirez-Hernandez et al. 2009). Sakurai and Mita (2011) developed a robot that can interact with people and collects information in biofied rooms. Ghys et al. (2006) and Rama et al.

(2009) developed 3D face recognition systems for multimedia applications. Svenstrup et al. (2009) developed a method to determine a person's pose by using laser range observations from robot navigation.

Several studies using laser range scanners were conducted for environments where people and mobile robots collaborate within the same physical space. In these studies, people were detected and tracked with laser range scanners, while 3D mapping was performed. This information was used for determining human movements constrains (Luber et al. 2011), based on an annotated data set (Zivkovic et al. 2008, Yang et al. 2011), based on leg detection (Bellotto and Hu 2009, Figure 6, Ramirez-Hernandez *et al.* 2009, Martinez-Otzeta *et al.* 2010), or based on Parametric Shape Modeling (Glas et al. 2009). In all these examples, precise collaboration is essential both for the effective operation and for safety.

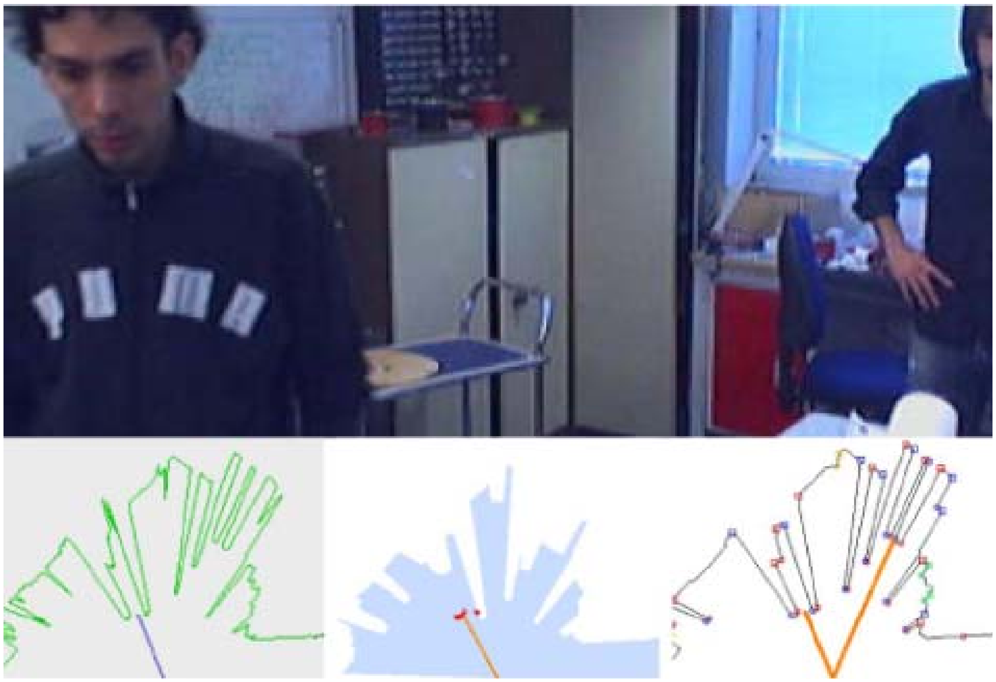


Figure 6. an example for leg detection using laser scanner (Bellotto and Hu 2009).

4.4 Precise Collaboration Function 4: Laser communication

In tasks requiring collaboration and interaction between mobile robots, laser-based communication can be the solution for the increasing demand for higher bandwidth. Research show that laser technology can enable the use of relatively higher bandwidth, lower power requirements, and increased potential for covert data links, in comparison to radio-based systems (Sofka et al. 2009). Currently, communication requires a visual contact between the robot transmitter and the robot receiver. This requirement constrains the agility and accurate steering of the laser beam over wide angular ranges. Furthermore, such systems need to resolve disturbances from optical platform vibrations and other atmospheric disturbances. The solutions proposed to compensate for this problems are based on using gimbals and gyroscopes (Marins et al. 2001),Omni-directional sensor assembly (Rosheim and Sauter 2002), high-speed non-mechanical laser beam steering devices (Nikulin et al. 2006) and a feedforward vibration rejection systems (Sofka et al. 2009).

4.5 Laser technology in support of collaboration

A summary of the research and applications of laser based systems supporting collaboration is given in Table 1. In all these cases, lasers are applied as: a tool, information medium, energy source, pointing device, or a sensor to collect data. In addition, it has been used as part of the collaboration process / collaborative system, or as a tool to be controlled by the collaborative system. Table 1 presents such systems grouped by their collaboration function.

Table 1: Research and applications survey of laser technology: (a) for collaboration; (b) controlled by a collaborative system.

Domain	**Application**	**Collaboration Activities**	**Collaboration Objectives**	**References**	**Role of Lasers**	**Laser Advantages**	**Collaboration Function***
Dental operations and surgery	Soft and Hard tissue: gingivectomies, gingivoplasties, operculectomies, biopsies, incising and draining procedures, vaporizing decay, etching enamel and dentin, desensitizing exposed root structure and creating temporary analgesia, frenectomies, treatment of aphthous ulcers and tissue welding.	No interaction, integration or collaboration	dental drill, dental decay prevention, tissue welding and decay detection,	(Boulnois 1986, Myers and McDaniel 1991, Wigdor *et al.* 1995, Yoo *et al.* 2010)	Tool	Minimizes cellular destruction, tissue swelling, and hemostasis; reduces need for anesthesia; reduces post-operative pain; circumvents the need for suturing	0
Manufacturing	Mechanical machining, cutting, laser processing	No interaction, integration or collaboration	Laser-based processing	(Brogardh 2009, Li	Tool	Lower cost and higher flexibility	0

				2010)			
Manufacturing	Automating CAD/CAM production,	CAD/CAM functions only	Measurement data acquisition	(Sickel *et al.* 2011)	scan, 3D modeling	Sensor advantages	0
Human Robot Interaction	Intelligent Chair Tool	Low level control	Obtain better position and orientation performance	(Faudzi *et al.* 2010)	measure actuator movement	Accurate positioning	0
Robots	Casualty extraction and care	Process control only	None	(Yoo *et al.* 2010)	chemical detection	Processing and data acquisition	0
Motion Controller	Ultra precision motion control	Laser sensor	Measurement accuracy only	(Shan *et al.* 2002)	Laser measurements	More precise motion control	0
Agriculture	automated vine cutting trans-planter	Interaction of systems	None	(Mazzetto and Calcante 2011)		Precise measurement	0
Mobile robots	People detection and tracking	Responsive collaboration / interaction	Improved HRI, human activity understanding, and intelligent cars.	(Luber *et al.* 2011)	Laser scanning, mapping,	Improved human tracking	1

					people detection		
Human-Robot Interaction	Dismantling interior facilities in buildings, wearable collaborative systems	Collaboration and interface functions, remote collaboration	Smoother, better quality execution of tasks, sensor based	(Mann 2000, Kurata *et al.* 2004, Cruz-Ramirez *et al.* 2008)	Point to a target with the laser pointer and laser spot	Accurate and fast marking, tracking moving objects accurately	1
Telerobots	Remote guidance	HRI, teleoperation	Intuitive interaction	(Livatino *et al.* 2010)	Mapping	Enabling precise guidance	2
Mobile / Social robots	Pose/ gestures detection, navigation, Feature scanning	HRI, corporal gestures	Precise cognition	(Ramirez-Hernandez *et al.* 2009, Svenstrup *et al.* 2009, Marcos *et al.* 2010)	laser range scanner, objects detection, face scanning	Accurate and fast data acquisition and response	2
Service / Manufact	Control for room cleaning, assisting in	Collaboration of techniques and direct	Enable intuitive control, improved	(Young Sang *et al.* 2008,	Mapping and objects	Control advantages, accurate and timely	1,2

uring robots	cases of chronic stroke	interaction	process control	Harb *et al.* 2009)	selection with laser pointer	data acquisition and transmission	
User Interface and HRI	Single Display Groupware (SDG), telerobotics, robot control, man-machine interface for intelligent presenter-audience collaborative environment	Collaborative and user interaction, Telerobotic manipulation	controlled laser pointers, interaction with multiple pointers, tele-operation guidance, specifying command and target location	(Park 2000, Oh and Stuerzlinger 2002, Vogt *et al.* 2004, Naren and Shaleen 2006, Ishii *et al.* 2009)	Input device for collaboration, laser pointers, laser beam projector, user interface	Interface advantages, ability to project targets, lower cost, lightweight, points accurately and reliable, user interface, accurate and timely sensing	1,2
Robots	positioning tasks	Mapping objects, positions	Joint team operations	(Gonzalez-Galvan *et al.* 2003)	Point to a work piece in the task space with the laser pointer	Accurate and timely sensing	1,2
Biofied rooms	acquire environmental information	HRI	Multi-sensor integration	(Sakurai and Mita 2011)	Laser scanning	Accurate and timely data acquisition	3

Human-Robot Interaction (HRI)	Localization, augmented reality	Interactive communication teleguide, HRI	Collaborative positioning, enable intuitive control	(Livatino *et al.* 2010, Morioka *et al.* 2012)	laser range scanner, mapping, obstacle detection, representation by color	Accuracy for better responsiveness, Accurate and timely data acquisition and transmission for stereoscopic visualization	3
Mobile robots	Navigation in urban areas, human detection and tracking, network surveillance	Multi-sensor integration, laser-sensed data transfer, HRI, collision avoidance	Better, safer team movements, joint team performance, multi-sensor integration	(Rongxin *et al.* 2008, Bellotto and Hu 2009, Li *et al.* 2011, Yang *et al.* 2011)	Laser scanning, mapping, detect people and people legs	Accurate, timely and fast scanning and multi-sensor data acquisition and transmission, accurate object detection and mapping	3
Social Robots	Calculate people trajectories	No interaction, integration or collaboration	Detecting people, people behavior	(Kanda *et al.* 2009)		Accurate and timely multi-sensor data acquisition	3
Mobile	Mapping , collaborative	Collaborative control,	integration of data	(Wenjian *et*	Laser	Accurate and timely	3

Robots	navigation, multi robot collaboration and cooperative Positioning	collaborative robots, tele-operation intelligent spatial interactions	from distributed sources, multi-sensor based mobility and collaboration, better performance,	*al.* 2009, Jarvis 2010, Rogers *et al.* 2011, Morioka *et al.* 2012, Tavakoli *et al.* 2012)	scanning, mapping, structured light, obstacle and people detection	data acquisition, maps and transmission, Tracking moving objects accurately	
Face Recognition	Multimedia	human-computer interaction	Precise face recognition, multi-sensor integration	(Ghys *et al.* 2006, Rama *et al.* 2009)	Face scanning	Accurate and timely sensing, data acquisition and transmission	3
Mobile robots	Navigation and tracking	Object recognition and obstacle avoidance	Observe partially available objects	(Tseng and Tang 2009)	Laser range scanner, mapping	Tracking moving objects accurately	1,3
Manufacturing and HRI	Laser-based tracking and human Detection and Tracking, laser welding,	HRI, AR, HR collaboration, laser sensors input	Obtain accurate data, better position and orientation details,	(Glas *et al.* 2009, Chuen Leong *et al.*	Laser welding, scanning and spot, detect	Accurate and timely tracking and data acquisition and	1,3

	path teaching		better welding quality	2010, Martinez-Otzeta *et al.* 2010)	people legs, human position	transmission	
Dental operations and surgery	augmented reality (AR) apparatus, projecting surgical plans onto patient	AR	More effective and accurate surgery	(Glossop *et al.* 2003)	Laser scanning and projecting and marking, distance measurements	Accurate and timely data acquisition and transmission	1,3
Augmented Reality	augmented reality apparatus,	AR	Multi-sensor integration	(Yeong Nam *et al.* 2009)	Laser scanning, projecting and marking, distance measurements	objects tracking and human action recognition	1,3
Mobile Robots	Mapping, localization, navigation, search and rescue	HRI, Robot collaboration, Mapping for collaboration, tracking,	responsive collaboration / interaction, Better	(Zivkovic *et al.* 2008, Guarnieri *et*	Laser scanning, mapping,	Accurate and timely data acquisition, maps and transmission,	2,3

		corporal posture detection	performance of robot team, HR teams,	*al.* 2009, Mehdi and Berns 2010, Zhuang *et al.* 2010, Cho and Lee 2012)	Structured light, motion state estimation, determine relative position,	accuracy for better responsiveness	
Human robot interaction	Pose/ gestures detection, HRI, AR, telerobotics	HRI, HR collaboration, gestures detection, user interface	Teleoperation guidance precise control, collaborative classification	(Giesler *et al.* 2004, Du *et al.* 2012, Wang *et al.* 2012)	Laser scanning, Structured light, object detection, mapping	Accurate processing by industrial robots, accurate and reliable detection and marking, accuracy for better control	2,3
Robots	Laser arc welding, path teaching	HR collaboration, Augmented reality	Collaboration among laser sensors, target marking, and laser processor	(Li *et al.* 2007)	Laser scanning, laser spot for marking and laser welding	Accurate processing by industrial robots	1,2,3

Mobile Robots	Development of pointing, acquisition, and tracking for laser communication	Development of control for pointing, acquisition, and tracking (PAT) system, multisensory interactions and communication	Joint team performance, better and precise performance	(Marins *et al.* 2001, Rosheim and Sauter 2002, Nikulin *et al.* 2006, Sofka *et al.* 2009)	Laser communication	Wider bandwidth, lower power requirements, and increased potential for covert data links in comparison to radio-based systems, accurate and timely data acquisition and transmission	4

* The collaboration functions as defined above as the four precision collaboration functions are: 0 -- Lasers are used with no collaboration so far; collaboration function 1 -- Targeting; collaboration function 2 -- Interaction; collaboration function 3 -- Mapping, localization and object detection; and, collaboration function 4 -- Laser-based communication.

5. OPPORTUNITIES AND CHALLENGES

Applying advanced laser techniques for precision collaboration will lead to new opportunities as described in Figure 2 and the review in Table 1. The review presents a combination of five collaboration dimensions, according to four attributes of collaboration: a. type of interaction; b. type of task; c. application; and, d. environment.

Each unique combination of collaboration, interaction, tasks, application, and environment will require specific communication; synchronization; gathering of environmental information; control characteristics (including commands, interactions, and interfaces); performance and status data evaluation, and in turn, specific laser characteristics and technology. The following section describes five dimensions of precise collaboration.

5.1 Collaboration Dimensions

We propose to classify precision collaboration and integration along five main dimensions, namely:

D1. Virtual Shared Surfaces Among Users: Conceptual design, sketching and planning

When physical design and development are required, team work is often necessary. Certain types of work can be carried out remotely. In such a context, the designers may be distributed and use a shared virtual model to accomplish a conceptual design, reflecting the characteristics of the physical objects manipulated through the interaction. In such contexts, accurate registration between the virtual spaces and the physical ones is crucial to assure that all the participants are working under the same coordinate system (Craig and Zimring 2002). This level of accuracy can be achieved only by projecting the regions of interest with lasers. Those regions of interests are the same surface regions on which one or more of the collaborating participants would sketch the conceptual model (Sareika and Schmalstieg 2007).

D2. Shared Spaces with Robots (Co-work): Pointing robots to targets

Assistive, service, and surveillance robots may interact with a user through verbal and non-verbal channels (gestures and speech commands (Breazeal *et al.* 2004)). In terms of gestures, the most common type is the deictic class, such as pointing to a location. When a pointing gesture is performed, a robot will move and pick the object indicated, or leave it at the pointed location (Sato *et al.* 2007). These systems suffer from ambiguity of target locations, especially when used outdoors. When a user intends to point to one location, by following its line of sight, the robot perceives a different location, typically due to the parallax effect (Cipolla and Hollinghurst 1996). In such situations, it is useful to have a laser mounted on a user's wrist to pinpoint an unambiguous target location, easily recognizable by the robot through computer vision systems.

D3. Shared Gestures: Pointing gestures

In the first dimension, laser projected points were used for common registration among different virtual views; nevertheless, the problem of representing accurately the sketches made by designers is not considered. These sketches are commonly designed on a projected surface (Ishii and Kobayashi 1992), such as the one provided by Microsoft Surface. A problem of this type of interactive displays is that the trajectories drawn over them are as thick as the fingers creating them. Still, some designs require thin links (trajectories) between the nodes representing instances of their model. An alternative approach is to sketch in the air, using a special glove that projects a single point coming from a laser installed on the user's palm (Fruchter *et al.* 2005).

By adopting such hardware/software combination, the trajectories represented by the movement of a finger or hand are translated into thin lines, resulting from the precise trajectory by the laser's dot projection (Jackson and Keefe 2011).

D4. Augmented Reality

Augmented reality is the virtual environment generated by integration of the captured views from cameras with objects superimposed on those images (Azuma 1997). Thus, users interact with virtual objects as if they were interacting with real ones. This technique has also been used to project textured patterns on real objects (Figure 7) lacking any patterns (e.g., uniform colors) in order to generate a realistic illusion of how the object would appear if it had that pattern (Leykin and Tuceryan 2004, Chuen Leong *et al.* 2010).

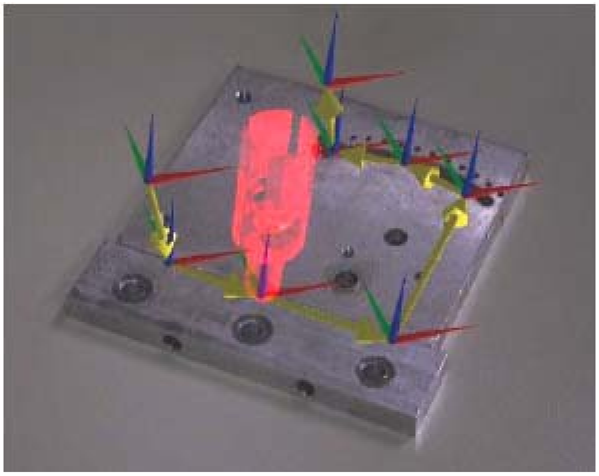


Figure 7. An example for a virtual tool overlaid on a real workpiece image (Chuen Leong et al. 2010).

In such scenarios, accurate registration between the object and the pattern is needed to assure a realistic view, rather than using only a lighting artifact. This registration is achieved by using a laser to render the desired edges/corners of the object, and set the boundaries of the projection (Lee et al. 2008).

D5. Shared Patterns: Projected structured light from individual sources to assess depth

Modern depth cameras use structured infra-red light projected on the environment to assess the distance of the objects within the environment to the camera (Salvi *et al.* 2004), such as the MS Kinect and Leap Motion sensors. This solution is cheap, precise and requires low energy consumption (Tsalakanidou *et al.* 2005), (Silberman and Fergus 2011). In spite of the revolutionary solution for depth imaging, this technology does not work outdoors due to the diffusion of the infra-red light, and the high interference with day light. To overcome this problem, a solution is to use lasers to generate the beam of light for projection on the environment. While this light is visible to the human eye, it can be filtered from the imaging system using the coefficients of signal in the frequency domain (Maimone and Fuchs 2012).

The five dimensions above are illustrated by collaborative applications based on visual cues, and can be generalized to other, non-visual types of information along the same five dimensions.

5.2 Research Needs and Opportunities

Initial progress in laser-based precision collaboration has been made, and also points to further opportunities and challenges. Thirteen key areas are shown in Table 2 along the above five collaboration dimensions, taken from application areas of industrial engineering, medicine, manufacturing, robotics, human robot interaction, and human computer interfaces. In these research areas and applications, lasers are used as a tool, information medium, energy source, pointing device and a sensor to collect data as part of the collaboration process / collaborative system, or as a tool to be controlled by the collaborative system.

Table 2. Emerging contribution and challenge areas for systems interaction, collaboration, and integration with lasers.

Collaboration Dimension	**Area / application**	**Function/Device**	**Sample References**
D1	Mobile robots / communication	Laser communication, development of pointing, acquisition, and tracking for laser communication	(Sofka *et al.* 2009)
D1-D2	Robot control	User interface, specifying command and target location; laser pointers	(Ishii *et al.* 2009)
D2	User interface and display groupware	Computer controlled laser pointers; Input device for collaboration	(Oh and Stuerzlinger 2002, Vogt *et al.* 2004);
D2	Mobile robots / intelligent space	Cooperative positioning, laser scanning, mapping, people detection	(Morioka *et al.* 2012)
D2	HRI	Dismantling interior facilities in buildings, pointing to a target in the task space with the laser pointer	(Cruz-Ramirez *et al.* 2008)
D2	Assistive robot (Chronic Stroke)	Selection of objects with laser pointer	(Young Sang *et al.* 2008).
D2-D3	Mobile / service robots, HRI	Pose/ gestures detection, laser range scanner, detection	(Ramirez-Hernandez *et al.* 2009)
D2-D3	HRI, Wearable collaborative systems	Collaboration/interface, point to real objects in the task space with laser spot, laser pointer	(Mann 2000, Kurata *et al.* 2004)
D2-D3	Industrial robots, positioning tasks	Mapping objects, point to a work piece in the task space with a laser pointer	(Gonzalez-Galvan *et al.* 2003)

D4	Industrial robots, laser welding, path teaching	HR collaboration, augmented reality, laser scanning, laser spotting for marking, laser welding	(Chuen Leong *et al.* 2010)
D4	Dental operations and surgery / AR	projecting surgical plans onto patient, laser scanning, projecting and marking	(Glossop *et al.* 2003)
D5	HRI, manipulator control, teleoperation, robot guidance	HR collaboration, user interface, gesture and posture detection	(Cho and Lee 2012, Du *et al.* 2012, Wang *et al.* 2012)
D5	Mobile robots	Multi robot collaboration, mapping and object detection	(Tavakoli *et al.* 2012)

While initial progress has been reported along these dimensions, further research is needed. Specifically, six frontier areas of need and opportunity are observed:

Area 1. Display groupware interfaces and synchronization

This area focuses on research of collaborative computer environment for multiple users that are physically in relative proximity, (e.g., Oh and Stuerzlinger 2002) and development of a framework that supports multiple pointing devices, such as mouse and laser pointer in graphical environments, (e.g., Vogt et al. 2004).

Area 2. Graphical representation, (e.g., Livatino et al. 2010, Sickel et al. 2011) and rendering using lasers, (e.g., Chuen Leong et al. 2010, Morioka et al. 2012).

Area 3. Gesture recognition using lasers, (e.g., Ishii et al. 2009, Ramirez-Hernandez et al. 2009, Svenstrup et al. 2009)

Lasers in combination with servo mirrors and photoreceptors have been used to track users' fingers. Their spatial and temporal information are used to recognize specific gestures.

Area 4. Human factors of integrated laser systems for collaboration, (e.g., Mann 2000, Kurata et al. 2004).

Area 5. Augmented reality using lasers

Laser projectors have been previously used to create Augmented Reality, (e.g., Glossop *et al.* 2003, Chuen Leong *et al.* 2010), instead of the standard head-mounted displays (HMD). This technology overcomes problems such as small field of view, limited resolution, multiple focus planes, and eye fatigue.

Area 6. Enhanced Depth Sensor

Technology is needed for indoor/outdoor use, e.g., (Miller et al. 2012): Monocular cameras using structured light are relatively cheap, reliable and do not require calibration. While some cameras deliver satisfactory performance indoors using IR structured light, other devices use stereoscopic (Kim et al. 2012), or rely on laser structured projections to deliver depth information (Chavez and Karstoft 2012).

In collaborative control theory (CCT) which is central to collaborative e-work, e-production and e-service systems (Nof 2003, Nof 2007), the use of laser technology can be considered as an enabler of better, more precise interaction for the purpose of collaborative activities. For example, laser-based interactions can improve the efficiency and effectiveness of the collaboration processes and the support protocols designed for optimized collaboration. They can also reduce the time required for interactions needed for collaboration, including set-up and trial interactions, and eliminate or reduce interaction-related errors and conflicts.

There are also key contributions to cyber-physical systems interaction with lasers. Lasers advantages and roles in interactive collaboration can reduce errors and conflicts, thus reducing the time of interaction, the number of interactions and commands required to achieve the collaboration goal, compared with less precise means of interaction. In addition, more precise collaboration based on lasers, as discussed above and illustrated in Tables 1 and 2 can increase the quality (precision) of the transmitted commands, hence reducing the number of resulting actions and improving the overall performance.

The following two examples illustrate the six opportunity areas.

i) **Welding robots path teaching example**: In a path teaching task of welding laser robots in an industrial environment, (e.g., Chuen Leong *et al.* 2010), the human-robot collaboration is conducted through augmented reality (AR). In this case, laser technology is used as:

- Processing tool -- laser welding;
- Sensor -- laser range scanner; and
- Marker -- laser pointer/spot.

A human-robot interaction (HRI) system has been designed by fusing information from a camera and a laser range finder. The laser range finder captures the Cartesian information given by a user, and the robot working paths and trajectories. An AR environment has been designed where the virtual tool is superimposed onto live video. The operator simply needs to point and click on the image of the workpiece, in order to generate the required welding tool path. A laser spot is marking the workpiece and then the workpiece is tracked by the system throughout the process (Chuen Leong *et al.* 2010).

In this example, the collaboration dimensions are: D1, D2 and D4.

ii) **Selective harvesting example**: Human-Robot collaborative task sharing system for selective harvesting (Bechar *et al.* 2012) can apply laser technology for:

- Cutting tool and energy transfer -- laser cutter;
- Sensing to detect fruits and obstacles -- laser range scanner;
- Targeting -- laser pointer; and
- Collaboration and interaction by detecting and tracking human operator/supervisor positions; tracking human operator's hands, and following human operator's commands with laser pointers, scanners and projected light.

In this example, the collaboration dimensions are: D1, D2, D3 and D5.

6. CONCLUSIONS AND RECOMMENDATIONS

Lasers play an important role in modern life, society and industry. Although laser technology has evolved for over 50 years, there are scientific and engineering challenges and areas that need to be explored for gaining further benefits with the advantages of laser technology (Li 2010).

The assimilation of lasers beyond communication, processing, and discovery to interaction and collaboration systems is still in its infancy. Only 0.12% of the reviewed papers published on lasers are devoted to these areas. Recent advances in laser technology raise the potential feasibility of harnessing certain laser solutions for new and improved integration through more precise interaction and collaboration systems. Precision and efficiency advantages of lasers include relatively more accurate and timely: sensory data and signals; control and communication of information; processing by accurate, fast, and efficient energy transfer and transmission.

Lasers can be applied in a collaborative mission as a tool to be monitored by the collaborative and interaction architecture, agents, or as part of the collaboration methodology. Laser-based collaboration and interaction are used in many areas, such as dental and medical operations and surgery, manufacturing, production, robotics, military, transportation, security, construction, and agriculture. So far, the use of lasers for precision collaboration and interaction is relatively limited; lasers are mainly applied as a tool to map the environment, detect objects, for targeting, localization.

Table 3 presents areas where laser-based interaction and collaboration are anticipated to grow in the near future, and their required collaboration dimensions. Harnessing lasers for precision collaboration is a significant and promising research area: It is expected to reduce costs, increase flexibility, and decrease system weight. Lasers will record, sense, mark, and inform about objects' topology accurately and with inherent precision. They are reliable, can transmit data at a wide bandwidth, low power requirements, and deliver efficiently high, focused energy. All these advantages can enable the implementation of effective precision collaborative systems.

Table 3. Laser-based interactions anticipated impact in eight emerging areas.

Impacts on safety, security, productivity, and quality	**Examples**	**Dimensions of Sharing Among Interacting Agents/Operators/Participants**				
		D1. Virtual Surfaces	**D2. Space with Robots**	**D3. Gestures**	**D4. Augmented Reality**	**D5. Patterns**

1. Manufacturing	Collaborative CAD/CAM production (Sickel *et al.* 2011); collaborative processing (Chuen Leong *et al.* 2010)	■	■		■	
2. Production	Facility monitoring for safety and quality (Ko *et al.* 2011); Sensor automation for safety and productivity (Jeong and Nof 2009)	■ ■	■ ■	■		■ ■
3. Agriculture	Precision human-robot tasks (Bechar *et al.* 2012)	■	■	■	■	■
4. Transportation	Airport security and safety (Chen *et al.* 2011)	■		■		■
5. Supply Chains	Supply chain security (Tkach *et al.* 2012)	■	■		■	■
6. Training	Security training (Velasquez and Nof 2009)	■			■	■
7. Healthcare	Operating Room image browser, robotic scrub nurse (Jacob *et al.* 2011)		■	■		

8. Environment	Environmental monitoring by laser-based wireless sensor networks (Liu *et al.* 2011)		■	■		■

Acknowledgement

Research reported in this chapter was partially supported by the PRISM Center at for Production, Robotics, and Integration Software for Manufacturing and Management at Purdue University, and by the Agricultural Robotics Lab at the Institute of Agricultural Engineering, Volcani Center.

References

Azuma, R.T., 1997. A survey of augmented reality. *Presence: Teleoperators and Virtual Environments,* 6 (4), 355-385 Available from: http://www.scopus.com/inward/record.url?eid=2-s2.0-0039560342&partnerID=40&md5=2b7be1cf8ae930ed6b3c3c3387555dc5.

Bechar, A., Meyer, J. & Edan, Y., 2009. An objective function to evaluate performance of human-robot collaboration in target recognition tasks. *IEEE Transactions on Systems Man and Cybernetics Part C-Applications and Reviews,* 39 (6), 611-620 Available from: <Go to ISI>://WOS:000270761100002.

Bechar, A., Wachs, J.P. & Nof, S.Y., 2012. Developing a human-robot collaborative system for precision agricultural tasks. *Proceedings of the 11th ICPA, International Conference on Precision Agriculture.* Indianapolis, IN.

Bellotto, N. & Hu, H., 2009. Multisensor-based human detection and tracking for mobile service robots. *IEEE Transactions on Systems Man and Cybernetics Part B-Cybernetics,* 39 (1), 167-181 Available from: <Go to ISI>://WOS:000262562700016.

Boulnois, J.L., 1986. Photophysical processes in recent medical laser developments: A review. *Lasers in Medical Sciences,* 1 (1), 47-66 Available from: <Go to ISI>://WOS:A1986C233900027.

Breazeal, C., Hoffman, G. & Lockerd, A., Year. Teaching and working with robots as a collaborationed.^eds. *Proceedings of the Third International Joint Conference on Autonomous Agents and Multiagent Systems*, 1030-1037.

Brogardh, T., 2009. Robot control overview: An industrial perspective. *Modeling Identification and Control,* 30 (3), 167-180 Available from: <Go to ISI>://WOS:000275358400007.

Cassinelli, A., Perrin, S. & Ishikawa, M., Year. Smart laser-scanner for 3d human-machine interfaceed.^eds. *Proceedings of the International Conference on Human Factors in Computing Systems*, Portland, OR, 1138-1130.

Chavez, A. & Karstoft, H., 2012. Improvement of kinect (tm) sensor capabilities by fusion with laser sensing data using octree. *Sensors,* 12 (4), 3868-3878 Available from: <Go to ISI>://WOS:000303309300006.

Chen, X.W., Landry, S.J. & Nof, S.Y., 2011. A framework of enroute air traffic conflict detection and resolution through complex network analysis. *Computers in Industry,* 62 (8-9), 787-794 Available from: <Go to ISI>://WOS:000297189100001.

Cho, K.B. & Lee, B.H., 2012. Intelligent lead: A novel hri sensor for guide robots. *Sensors,* 12 (6), 8301-8318 Available from: <Go to ISI>://WOS:000305801400081.

Chuen Leong, N., Teck Chew, N., Thi Anh Ngoc, N., Yang, G. & Chen, W., 2010. Intuitive robot tool path teaching using laser and camera in augmented reality environment. *Proceedings of the 11th International Conference on Control, Automation, Robotics and Vision.* 114-119.

Cipolla, R. & Hollinghurst, N.J., 1996. Human-robot interface by pointing with uncalibrated stereo vision. *Image and Vision Computing,* 14 (3), 171-178 Available from: http://www.scopus.com/inward/record.url?eid=2-s2.0-0030123787&partnerID=40&md5=6e7ff85137c31d340fe321b8d3e3325d.

Craig, D.L. & Zimring, C., 2002. Support for collaborative design reasoning in shared virtual spaces. *Automation in Construction,* 11 (2), 249-259 Available from: <Go to ISI>://WOS:000172760800012.

Cruz-Ramirez, S.R., Ishizuka, Y., Mae, Y., Takubo, T. & Arai, T., Year. Dismantling interior facilities in buildings by human robot collaborationed.^eds. *Proceedings of the 2008 IEEE International Conference on Robotics and Automation, Vols 1-9*, Pasadena, CA, 2583-2590.

Du, G.L., Zhang, P., Mai, J.H. & Li, Z.L., 2012. Markerless kinect-based hand tracking for robot teleoperation. *International Journal of Advanced Robotic Systems,* 9, 10 Available from: <Go to ISI>://WOS:000306516700001.

Faudzi, A.A.M., Suzumori, K. & Wakimoto, S., 2010. Development of an intelligent chair tool system applying new intelligent pneumatic actuators. *Advanced Robotics,* 24 (10), 1503-1528 Available from: <Go to ISI>://WOS:000279366100008.

2005. *Divas-a cross-media system for ubiquitous gesture-discourse-sketch knowledge capture and reuse*.

Ghys, C., Paragios, N. & Bascle, B., Year. Graph-based multi-resolution temporal-based face reconstructioned.^eds. *Proceedings of the Advances in Visual Computing, Pt 1*, Lake Tahoe, NV, 803-812.

Giesler, B., P., S., M., W. & Dillmann, R., Year. Sharing skills: Using augmented reality for human-robot collaborationed.^eds. *Proceedings of the SPIE*, 446-453.

Glas, D.F., Miyashita, T., Ishiguro, H. & Hagita, N., 2009. Laser-based tracking of human position and orientation using parametric shape modeling. *Advanced Robotics,* 23 (4), 405-428 Available from: <Go to ISI>://WOS:000264391000003.

Glossop, N., Wedlake, C., Moore, J., Peters, T. & Wang, Z.H., Year. Laser projection augmented reality system for computer assisted surgeryed.eds. *Proceedings of the Medical Image Computing and Computer-Assisted Intervention - Miccai 2003, Pt 2*, 239-246.

Gonzalez-Galvan, E.J., Cruz-Ramirez, S.R., Seelinger, M.J. & Cervantes-Sanchez, J.J., 2003. An efficient multi-camera, multi-target scheme for the three-dimensional control of robots using uncalibrated vision. *Robotics and Computer-Integrated Manufacturing,* 19 (5), 387-400 Available from: <Go to ISI>://WOS:000185422300001.

Guarnieri, M., Kurazume, R., Masuda, H., Inoh, T., Takita, K., Debenest, P., Hodoshima, R., Fukushima, E. & Hirose, S., Year. Helios system: A team of tracked robots for special urban search and rescue operationsed.^eds. *Proceedings of the 2009 IEEE-RSJ International Conference on Intelligent Robots and Systems*, 2795-2800.

Harb, M., Abielmona, R. & Petriu, E., Year. Speed control of a mobile robot using neural networks and fuzzy logiced.^eds. *Proceedings of the 2009 International Joint Conference on Neural Networks, Vols 1- 6*, New York, NY: IEEE, 1346-1352.

Ishii, H. & Kobayashi, M., Year. Clearboard: A seamless medium for shared drawing and conversation with eye contacted.^eds. *Proceedings of the Conference on Human Factors in Computing Systems*, 525-532.

Ishii, K., Zhao, S., Inami, M., Igarashi, T. & Imai, M., Year. Designing laser gesture interface for robot controled.^eds. *Proceedings of the 12th IFIP International Conference on Human-Computer Interaction*, Uppsala, Sweden, 479-492.

Jackson, B. & Keefe, D.F., Year. Sketching over props: Understanding and interpreting 3d sketch input relative to rapid prototype propsed.^eds. *Proceedings of the IUI 2011 Sketch Recognition Workshop*.

Jacob, M.G., Li, Y.T. & Wachs, J.P., Year. A gesture driven robotic scrub nurseed.^eds. *Proceedings of the IEEE International Conference on Systems, Man and Cybernetics*, 2039-2044.

Jarvis, R., Year. Terrain-aware path guided mobile robot teleoperation in virtual and real spaceed.^eds. *Proceedings of the Third International Conference on Advances in Computer-Human Interactions: ACHI 2010*, 56-65.

Jeong, W. & Nof, S.Y., 2009. A collaborative sensor network middleware for automated production systems. *Computers and Industrial Engineering,* 57 (1), 106-113 Available from: <Go to ISI>://WOS:000267518000011.

Jiang, R. & Chen, Y., Year. Multirobot precise localization based on multisensor fusioned.^eds. *Proceedings of the 2008 IEEE Conference on Robotics, Automation, and Mechatronics*, Chengdu, Chaina, 967-972.

Kanda, T., Glas, D.F., Shiomi, M. & Hagita, N., 2009. Abstracting people's trajectories for social robots to proactively approach customers. *IEEE Transactions on Robotics,* 25 (6), 1382-1396 Available from: <Go to ISI>://WOS:000272490100014.

Kemp, C.C., Anderson, C.D., Nguyen, A.J. & Xu, Z., 2008. A point and click interface for the real world: Laser designation of objects for mobile manipulation. *Proceedings of the 3rd ACM/IEEE International conference on Human-Robot Interaction.* 241-248.

Kim, H., Lee, G.A., Yang, U., Kwak, T. & Kim, K.H., 2012. Dual autostereoscopic display platform for multi-user collaboration with natural interaction. *Etri Journal,* 34 (3), 466-469 Available from: <Go to ISI>://WOS:000305206900020.

Ko, H.S., Wachs, J.P. & Nof, S.Y., 2011. Web-based facility monitoring system using wireless sensor network. *Proceedings of the Industrial Engineering Research Conference.* Reno, NV.

Kurata, T., Sakata, N., Kourogi, M., Kuzuoka, H. & Billinghurst, M., Year. Remote collaboration using a shoulder-worn active camera/lasered.^eds. *Proceedings of the 8th International Symposium on Wearable Computers*, Arlington, VA, 62-69.

Lee, J.C., Hudson, S.E. & Tse, E., Year. Foldable interactive displaysed.^eds. *Proceedings of the 21st Annual ACM Symposium on User Interface Software and Technology*, 287-290.

Leykin, A. & Tuceryan, M., Year. Automatic determination of text readability over textured backgrounds for augmented reality systemsed.^eds. *Proceedings of the Third IEEE and ACM International Symposium on Mixed and Augmented Reality*, 224-230.

Li, G., Du, J., Zhu, C. & Sheng, W., Year. A cost-effective and open mobile sensor platform for networked surveillanceed.^eds. *Proceedings of the Conference on Signal and Data Processing of Small Targets*, San Diego, CA: SPIE.

Li, H.C., Gao, H.M. & Wu, L., 2007. Teleteaching approach for sensor-based arc welding telerobotic system. *Industrial Robot-an International Journal,* 34 (5), 423-429 Available from: <Go to ISI>://WOS:000249620500017.

Li, L., 2010. The challenges ahead for laser macro, micro and nano manufacturing. *In* Lawerence, J., Pou, J., Low, D.K.Y. & Toyserkani, E. eds. *Advances in laser materials processing: Technology, research and applications.* Cambridge: Woodhead Publishing Limited, 20-39.

Liu, S.C., Gao, L., Yin, Z.W., Shi, Y.C., Zhang, L., Chen, X.F. & Cheng, J.C., 2011. Simple hybrid wire-wireless fiber laser sensor by direct photonic generation of beat signal. *Applied Optics,* 50 (12), 1792-1797 Available from: <Go to ISI>://WOS:000289723600020.

Livatino, S., Muscato, G., De Tommaso, D. & Macaluso, M., Year. Augmented reality stereoscopic visualization for intuitive robot teleguideed.^eds. *Proceedings of the IEEE International Symposium on Industrial Electronics (ISIE 2010)*, Bari, ITALY: IEEE, 2828-2833.

Luber, M., Tipaldi, G.D. & Arras, K.O., 2011. Place-dependent people tracking. *International Journal of Robotics Research,* 30 (3), 280-293 Available from: <Go to ISI>://WOS:000287650400003.

Maimone, A. & Fuchs, H., Year. Reducing interference between multiple structured light depth sensors using motioned.^eds. *Proceedings of the IEEE Virtual Reality*, 51-54.

Mann, S., Year. Telepointer: Hands-free completely self contained wearable visual augmented reality without headwear and without any infrastructural relianceed.^eds. *Proceedings of the 4th International Symposium on Wearable Computers*, Atlanta, GA, 177-178.

Marcos, S., Gomez-Garcia-Bermejo, J. & Zalama, E., 2010. A realistic, virtual head for human-computer interaction. *Interacting with Computers,* 22 (3), 176-192 Available from: <Go to ISI>://WOS:000276328600003.

Marins, J.L., Xiaoping, Y., Bachmann, E.R., Mcghee, R.B. & Zyda, M.J., Year. An extended kalman filter for quaternion-based orientation estimation using marg sensorsed.^eds. *Proceedings of the IEEE Intelligent Robots and Systems*, 2003-2011 vol.4.

Martinez-Otzeta, J.M., Ibarguren, A., Ansuategi, A., Tubio, C. & Aristondo, J., Year. People following behaviour in an industrial enviroment using laser and stereo cameraed.^eds. *Proceedings of the 23rd International Conference on Industrial, Engineering and Other Applications of Applied Intelligent Systems*, Cordoba, Spain, 508-517.

Mazzetto, F. & Calcante, A., 2011. Highly automated vine cutting transplanter based on dgnss-rtk technology integrated with hydraulic devices. *Computers and Electronics in Agriculture,* 79 (1), 20-29 Available from: <Go to ISI>://WOS:000296308000003.

Mehdi, S.A. & Berns, K., Year. Ordering of robotic navigational tasks in home environmented.^eds. *Proceedings of the 13th Federation-of-International-Robot-soccer-Association Robot World Congress*, Bangalore, India: Springer-Verlag Berlin, 242-249.

Miller, A., White, B., Charbonneau, E., Kanzler, Z. & Laviola, J.J., 2012. Interactive 3d model acquisition and tracking of building block structures. *IEEE Transactions on Visualization and Computer Graphics,* 18 (4), 651-659 Available from: <Go to ISI>://WOS:000301526500019.

Jacob, M, Cange, C., Packer, R. & Wachs, J., Year. Intention, context and gesture recognition for sterile mri navigation in the operating roomed.^eds. *Proceedings of the Progress in Pattern Recognition, Image Analysis, Computer Vision, and Applications*, 220-227.

Jacob, M., Wachs, J. & Packer, R., 2012b. Hand-gesture-based sterile interface for the operating room using contextual cues for the navigation of radiological images. *Journal of the American Medical Informatics Association*

Morioka, K., Oinaga, Y. & Nakamura, Y., 2012. Control of human-following robot based on cooperative positioning with an intelligent space. *Electronics and Communications in Japan,* 95 (1), 20-30 Available from: <Go to ISI>://WOS:000298484700003.

Myers, T.D. & Mcdaniel, J.D., 1991. The pulsed nd:Yag dental laser: Review of clinical applications. *Journal of the California Dental Association,* 19 (11), 25-30 Available from: <Go to ISI>://MEDLINE:1725987.

Naren, V. & Shaleen, V., 2006. Towards development of a non-touch man-machine interface for intelligent presenter-audience collaborative environment. *ASME Conference Proceedings,* 2006 (42578), 841-849 Available from: http://link.aip.org/link/abstract/ASMECP/v2006/i42578/p841/s1
http://dx.doi.org/10.1115/DETC2006-99267.

Nikulin, V., Khandekar, R., Sofka, J. & Mecherle, G.S., Year. Performance of a laser communication system with acousto-optic tracking : An experimental studyed.^eds. *Proceedings of SPIE, the International Society for Optical Engineering*SPIE, 61050C.1-61050C.10.

Nof, S.Y., 2003. Design of effective e-work: Review of models, tools, and emerging challenges. *Production Planning and Control,* 14 (8), 681-703 Available from: <Go to ISI>://WOS:000220517000002.

Nof, S.Y., 2007. Collaborative control theory for e-work, e-production, and e-service. *Annual Reviews in Control,* 31 (2), 281-292 Available from: <Go to ISI>://WOS:000251951600009.

Nof, S.Y., 2011. Cultural factors: Their impact in collaboration support systems and on decision quality. *In* Proctor, R.W., Nof, S.Y. & Yih, Y. eds. *Cultural factors in systems design, decision making and action.* CRC Press.

Oh, J.Y. & Stuerzlinger, W., Year. Laser pointers as collaborative pointing devicesed.^eds. *Proceedings of the Graphics Interface 2002 Conference*, Calgary, Canada, 141-149.

Park, Y.S., Year. Structured beam projection for semi-automatic teleoperationed.^eds. *Proceedings of the Conference on Optomechatronic Systems*, Boston, MA, 192-201.

Perrin, S., Cassinelli, A. & Ishikawa, M., Year. Gesture recognition using laser-based tracking systemed.^eds. *Proceedings of the 6th IEEE International Conference on Automatic Face and Gesture Recognition*, Seoul, South Korea, 541-546.

Rama, A., Tarres, F. & Rurainsky, J., 2009. 2d-3d pose invariant face recognition system for multimedia applications. *In* Grgic, M., Delac, K. & Ghanbari, M. eds. *Recent advances in multimedia signal processing and communications.* Berlin: Springer, 121-144.

Ramirez-Hernandez, A.C., Rivera-Bautista, J.A., Marin-Hernandez, A. & Garcia-Vega, V.A., 2009. *Detection and interpretation of human walking gestures for human-robot interaction* New York: IEEE.

Rogers, J., Paluri, M., Cunningham, A., Christensen, H.I., Michael, N., Kumar, V., Ma, J. & Matthies, L., 2011. Distributed autonomous mapping of indoor environments. *Proceedings of the Conference on Micro- and Nanotechnology Sensors, Systems, and Applications III.* Orlando, FL: SPIE-Int Soc Optical Engineering.

Rongxin, J., Xiang, T., Li, X. & Yaowu, C., Year. A robot collision avoidance scheme based on the moving obstacle motion predictioned.^eds. *Proceedings of the International Colloquium on Computing, Communication, Control, and Management*, 341-345.

Rosheim, M.E. & Sauter, G.F., Year. New high-angulation omni-directional sensor mounted.^eds. *Proceedings of the Free-Space Laser Communication and Laser Imaging II*, Seattle, WA: SPIE, 163-174.

Sakurai, F. & Mita, A., Year. Biofied room integrated with sensor agent robots to interact with residents and acquire environmental informationed.^eds. *Proceedings of the Conference on Sensors and Smart Structures Technologies for Civil, Mechanical, and Aerospace Systems 2011*, San Diego, CA: SPIE; Amer Soc Mech Engineers; KAIST.

Salvi, J., Pag፤¨S, J. & Batlle, J., 2004. Pattern codification strategies in structured light systems. *Pattern Recognition,* 37 (4), 827-849 Available from: http://www.scopus.com/inward/record.url?eid=2-s2.0-1542286514&partnerID=40&md5=0e776b54cf8bd1eea660daf6d9590b86.

Sareika, M. & Schmalstieg, D., Year. Urban sketcher: Mixed reality on site for urban planning and architectureed.^eds. *Proceedings of the 2007 6th IEEE and ACM International Symposium on Mixed and Augmented Reality, ISMAR*, 27-30.

Sato, E., Yamaguchi, T. & Harashima, F., 2007. Natural interface using pointing behavior for human-robot gestural interaction. *IEEE Transactions on Industrial Electronics,* 54 (2), 1105-1112 Available from: <Go to ISI>://WOS:000245518900043.

Shan, X.M., Kuo, S.K., Zhang, J.H. & Menq, C.H., 2002. Ultra precision motion control of a multiple degrees of freedom magnetic suspension stage. *IEEE-ASME Transactions on Mechatronics,* 7 (1), 67-78 Available from: <Go to ISI>://WOS:000174454200008.

Sickel, K., Baloch, S., Melkisetoglu, R., Bubnik, V., Azernikov, S. & Fang, T., 2011. Toward automation in hearing aid design. *Computer-Aided Design,* 43 (12), 1793-1802 Available from: <Go to ISI>://WOS:000299134900021.

Silberman, N. & Fergus, R., Year. Indoor scene segmentation using a structured light sensored.^eds. *Proceedings of the IEEE International Conference on Computer Vision*, 601-608.

Sofka, J., Nikulin, V.V., Skormin, V.A., Hughes, D.H. & Legare, D.J., 2009. Laser communication between mobile platforms. *IEEE Transactions on Aerospace and Electronic Systems,* 45 (1), 336-346 Available from: <Go to ISI>://WOS:000265376100026.

Suzuki, T., Ohya, A. & Yuta, S., Year. Operation direction to a mobile robot by projection lightsed.^eds. *Proceedings of the 2005 IEEE Workshop on Advanced Robotics and its Social Impacts*, 160-165.

Svenstrup, M., Tranberg, S., Andersen, H.J. & Bak, T., Year. Pose estimation and adaptive robot behaviour for human-robot interactioned.^eds. *Proceedings of ICRA: 2009 IEEE International Conference on Robotics and Automation, Vols 1-7*, New York, NY: IEEE, 3222-3227.

Tavakoli, M., Cabrita, G., Faria, R., Marques, L. & De Almeida, A.T., 2012. Cooperative multi-agent mapping of three-dimensional structures for pipeline inspection applications. *International Journal of Robotics Research,* 31 (12), 1489-1503 Available from: <Go to ISI>://WOS:000311643300009.

Tkach, I., Edan, Y. & Nof, S.Y., Year. Security of supply chains by automatic multi-agents collaborationed.^eds. *Proceedings of the INCOM*, Bucharest, Romania.

Tsalakanidou, F., Malassiotis, S. & Strintzis, M.G., 2005. Face localization and authentication using color and depth images. *IEEE Transactions on Image Processing,* 14 (2), 152-168 Available from: http://www.scopus.com/inward/record.url?eid=2-s2.0-13244258407&partnerID=40&md5=bb61815308618ca43ef19defd0e576aa.

Tseng, K.-S. & Tang, A.C.-W., 2009. Self-localization and stream field based partially observable moving object tracking. *Eurasip Journal on Advances in Signal Processing,* 2009, 12 Available from: <Go to ISI>://WOS:000267449600001.

Velasquez, J.D. & Nof, S.Y., 2009. Best-matching protocols for assembly in e-work networks. *International Journal of Production Economics,* 122 (1), 508-516 Available from: <Go to ISI>://WOS:000271116400048.

Vogt, F., Wong, J., Po, B.A., Argue, R., Fels, S.S. & Booth, K.S., Year. Exploring collaboration with group pointer interactioned.^eds. *Proceedings of the Computer Graphics International*, 636-639.

Wachs, J., Stern, H., Edan, Y., Gillam, M., Feied, C., Smith, M. & Handler, J., 2007. Gestix: A doctor-computer sterile gesture interface for dynamic environments. *Advances in Soft Computing,* 39, 30-39 Available from: http://www.scopus.com/inward/record.url?eid=2-s2.0-58149236989&partnerID=40&md5=7fac8ced82cc2c04160ccfedcf9099a7.

Wachs, J.P., Stern, H.I., Edan, Y., Gillam, M., Handler, J., Feied, C. & Smith, M., 2008. A gesture-based tool for sterile browsing of radiology images. *Journal of the American Medical Informatics Association,* 15 (3), 321-323 Available from: http://www.scopus.com/inward/record.url?eid=2-s2.0-43049130356&partnerID=40&md5=ed6bf0e3d9fed3d66f80bb74cc20036a.

Wang, B.C., Li, Z.J., Ye, W.J. & Xie, Q., 2012. Development of human-machine interface for teleoperation of a mobile manipulator. *International Journal of Control Automation and Systems,* 10 (6), 1225-1231 Available from: <Go to ISI>://WOS:000311713500017.

Wenjian, Y., Fuchun, S., Huaping, L. & Yu, S., Year. A collaborative navigation system for autonomous vehicle in flat terrained.^eds. *Proceedings of the IEEE International Conference on Control and Automation*, Christchurch, New Zealand: IEEE, 1615-1620.

Wigdor, H.A., Walsh, J.T., Featherstone, J.D.B., Visuri, S.R., Fried, D. & Waldvogel, J.L., 1995. Lasers in density. *Lasers in Surgery and Medicine,* 16 (2), 103-133 Available from: <Go to ISI>://WOS:A1995QN91700001.

Wos, 2012. Web of science.

Yang, S.-W., Wang, C.-C. & Thorpe, C., 2011. The annotated laser data set for navigation in urban areas. *International Journal of Robotics Research,* 30 (9), 1095-1099 Available from: <Go to ISI>://WOS:000294156100001.

Yeong Nam, C., Young-Ho, K., Jin, C., Kyusung, C. & Hyun, S.Y., 2009. An adaptive sensor fusion based objects tracking and human action recognition for interactive virtual environments. *Proceedings of the 8th International Conference on Virtual Reality Continuum and its Applications in Industry.* Yokohama, Japan: ACM.

Ying, W., Sun, F., Liu, H. & Song, Y., Year. A collaborative navigation system for autonomous vehicle in flat terrained.^eds. *Proceedings of the IEEE International Conference on Control and Automation*, Christchurch, New Zealand, 1615-1620.

Yoo, A.C., Gilbert, G. R. & Broderick, T.J., 2010. *Military robotic combat casualty extraction and care* New York: Springer.

Young Sang, C., Cressel, D.A., Jonathan, D.G. & Charles, C.K., 2008. Laser pointers and a touch screen: Intuitive interfaces for autonomous mobile manipulation for the motor impaired. *Proceedings of the 10th international ACM SIGACCESS conference on Computers and accessibility.* Halifax, Canada: ACM.

Zhuang, Y., Gu, M.W., Wang, W. & Yu, H.Y., 2010. Multi-robot cooperative localization based on autonomous motion state estimation and laser data interaction. *Science China-Information Sciences,* 53 (11), 2240-2250 Available from: <Go to ISI>://WOS:000283362900008.

Zivkovic, Z., Booij, O., Krose, B., Topp, E.A. & Christensen, H.I., 2008. From sensors to human spatial concepts: An annotated data set. *IEEE Transactions on Robotics,* 24 (2), 501-505 Available from: <Go to ISI>://WOS:000254705600026.