Towards Coexistence of Human and Robot: How Ubiquitous Computing Can Contribute?

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Abstract. After the ISO 10218-1/2 in 2011, safety factors for industry robot are standardized. As robotics expands its area from industry further into service, educational, healthcare and etc., both human and robot are exposed to a space with more openness and less certainty. Because there is no common safety specification, we raise in this paper our own hypotheses on the safety requirements in dense human-robot co-existing scenarios and focus more on demonstrating the possibilities provided by the research field named Ubiquitous Computing.

1 Introduction

The number of robots over the world keeps on growing. According to the World Robotics studies [1], 159,346 units of industry robots were sold in 2013, 16,067 professional service robots and about 3,000,000 personal and domestic use robots were sold in 2012. As robots' population grows, the physical even emotional contacts between robots and human are also growing, freeing human from certain labor work and meanwhile bringing potential risks. As in early ages robots were implemented mainly in industry, safety specifications have been developed mainly for industrial robots, e.g. ISO 10218-1/2:2011 sets the rule on both robot itself, the robot system and integration [2] [3]; in US the under revision ANSI/RIA R.15.06-2012 re-opens the allowance of human and robot working in a loop. In industry, the general trend shifts from strict isolation of robot from human to detailed specifications on reducing hazards. Out side of industry, however, robots are already in close contact with human, especially in the case of service robot. Since there is no fixed global specification till now, researchers follow their own ideas on whether and how to separate robot from public audience at Expo's and demonstrations. Domestic-use robot providers take care of human by hiding rigid components inside, reducing the robot's weight and speed, and implementing obstacle detecting sensors.

Ubiquitous computing as a fast developing field focuses on pushing the one central powerful computer to multiple little computing units into the environment and onto human beings. This indicates tiny sensing and processing units, and naturally, the application field of environment and human activity monitoring, which are also important factors a robot might need, when comes to dense contact with human beings.

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We perform an initial survey on what exists in Ubiquitous computing and could be used by robotics in this paper. The contribution lies in:

1) we analyze and raise our own hypotheses on the safety requirements in dense human-robot co-existing scenarios;

2) we perform a survey on possibilities provided by Ubiquitous Computing, the merging of which and robotics could potentially support dense human-robot co-existence.

2 Hazards in Dense Human-Robot Co-existing Scenarios

Vasic and etc. gave a detailed survey on safety issues in human-robot interactions [4]. Starting from industry, the danger comes when human gets trapped between robot and an object (e.g. a wall) or when human comes into collision with a robot [5]. A detailed list of significant hazards can be found in ISO 10218-1 as annex, including: Mechanical, electrical, thermal, noise, vibration, radiation, material/substance, ergonomic, the hazards associated with environment and combined hazards. The hazard should be analyzed and minimized from technical points of view, however, in the real applications, there are still unexpected errors and failures which can not be exactly predicted:

- mechanics failure: aging of motors, connectors;
- electronics failure: aging of components and isolation material, out of power half the way of operation;
- program failure: program bugs, untested scenarios;
- operational error: untrained engineers, operators, and users;

Besides regular maintenance, the above listed hazards are minimized in industry applications by:

- strictly pre-defined environment and space (robot cell);
- strictly pre-defined operation routine;
- authorization of properly trained operators, maintenance workers and programers;
- speed limitation when human is present;
- protective stop function and an independent emergency stop function.

While robot go out to factory and into family or other social areas, the above conventional rules become invalid. The situation is similar to that of computer going from military use to civil and then personal use. The difference is however the actuation, the capability of active physical movement brings more potential hazards. Moreover, the robot enters an open environment where changes may happen anytime and anyhow, the users are most often non-professional and unexperienced people. Animals (e.g. pets) might come into close contact with the robot, which might even bring damage to robot. (e.g. a child might see a home service robot and pour water onto it just out of curiosity.) Due to these obstacles, the most sold service robot now is still household robots, which are small in size, carry out comparatively simple and fixed tasks.

In general, to avoid potential damage to human and to itself, a robot in dense coexistence and frequent contact with human needs to know:

Who I am discover identification, including itself, the human being(s) and possible other robot nearby;
Where I am discover context, viz. gather by itself or from environment useful information;
How to work adapt to environment and be able to find the balance between performance and potential hazard level;
How to survive protect first human then itself from damage.

3 Key Factors and Ubiquitous Computing Solutions

Ubiquitous Computing (or in other names: Pervasive Computing, Internet of Things, Ambient Intelligence) is a concept raised by Mark Weiser first in the late 80's [6], "where computing is made to appear everywhere and anywhere." The questions raised above can be mapped into several key factors in Ubiquitous Computing accordingly and listed below.

3.1 Identification

Identification is like a key or a pointer which is linked to further information: parameters of the owner, history and trace, allowance to access databank or use certain resources. The available solution includes:

- **Barcode**: Printed or displayed 1D or 2D machine readable image, with numbers and letters embedded. A camera plus corresponding algorithm can read the information quickly and very reliably. Thanks to the almost neglectable cost (printed on a paper or displayed on a screen), it is widely used in registration system like tickets, good tags in supermarket, book numbering. The code however, must be put to the surface and facing the reader, viz. the tagged object can not be read when it is inside a container or blocked by other objects.
- **Radio-frequency identification (RFID)**: Information transferred wirelessly through electromagnetic fields, the system is composed of a Tag and a reader. The RFID tag where information is stored can be flat, small and bendable. RFID system over-performs barcode in that it doesn't have to be exposed, because electromagnetic field can transmit through most of the material. Active tags with battery enable a higher communication range and passive tags offer a lower cost. RFID tags are used in shipping and on production lines to track goods, or embedded in ID cards for an unique identification of the owner. In research, it is used for indoor-localization [7], to identify which object is being used [8] or to track where the the object is [9].
- **Face recognition and optical character recognition (OCR)**: Barcode and RFID tag need to be attached additionally to object or human, who is willing to show his/her/its identity. In most of the dynamic scenarios (e.g.

in a classroom or restaurant), the up-to-date default setting still doesn't assure most of the people and objects provide his/her/its own identification. Via facial or voice recognition, human can be recognized. With OCR, text printed on an object can be recognized. There are mass amount of research done in all the three directions, even real-time face recognition on wearable device is now possible [10].

3.2 Context

Context, according to Dey's definition [11], is:

"any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves."

Human is able to feel the environment through sensations (vision, sound, balance, touch, smell, taste, temperature, pain), analyze the situation with the brain, store the abstract information, and use the information real-timely or later to improve performance or avoid hazardous situation. For computer or robot, this is not completely straightforward. Depending on the robot's task, some sensation might be unnecessary.

However, one basic requirement to enable coexistence of robot and human is to avoid collision. This is valid for all the service robots, whatever task it has, and can be grouped into three levels:

- **a) Avoid damage when collides**: the robot should slow down or stop when it is already in direct contact with a person.
- **b) Avoid collision**: The robot should avoid entering the void range of a person when planning its movement path, and slow down already before possible collision with human. A broad research on pre-collision safety strategies can be found in [12].
- **c) Avoid secondary damage**: The robot should detect challenging situation and try to avoid it (e.g. rugged floor or running pets), which might results in the robot's falling then unexpected and uncontrolled collision, either from the falling robot or flying away item the robot is carrying (e.g. a cup of hot coffee) d. This also includes decision at critical point, to not collide into a second person when retreating from the collision with the first person.

The key parameters involved here include:

- **Force**: Force can be detected either independently through torque sensing in the joint [13] or through pressure sensitive artificial skin [14]. These techniques stands as the last guard when collision is already happening.
- **Distance and Localization**: It is safer however to stop or change direction already from a distance. Some sensors are already used in distance measuring on robot, e.g. laser and infrared [15], time of flight of sound [16]. Visual information has already been used in the last century for building an environment map [17].

There are many other localization methods developed in Ubiquitous computing: GPS is already a common means for outdoor localization. Indoor localization using time of arrival of ultrawideband (UWB) signal [18] enjoys a very high precision but is limited to simple room setup, because reflections from furnitures and people mess up the original signal. WIFI based indoor localization locates the user by matching the local signal strength to a pre-built signal strength map [19]. Inertial unit (accelerometer and gyroscope) combined with WIFI signals and GPS (for a concrete coordinate when entering and leaving the building) can be used to further improve in-door map and localization precision [20] [21]. Magnetic coupling sensor replaces the map of WIFI signal with a field generated by the coils at a certain frequency, which is hardly influenced by normal environment, thus is very robust [22]. Zhou and etc. proposed a large area high spacial precision pressure sensing matrix, which may provide a real-time obstacle map [23]. Whereas capacitive sensing have been used as touchless input interface [24], it can be used as an emergent trigger when the robot enters into void range of human (viz. cm level). 3-D motion input device based on multiple infrared projector(s) and camera(s) are used for gesture control with limbs and fingerssong2008vision, they can be used for distance measuring between robot and human, too. Also robot itself is used to build up indoor/outdoor maps [25].
- **Warning**: If the robot is not able to avoid collision by itself, it should warn human beings which might be involved in or influenced by the collision, either through vibration, sound of a wearable device, or through audio or visual warning from the robot itself or in the environment.

Beside the key techniques listed above, in ubiquitous and wearable computing, there are already plenty of sensor systems and data mining algorithms designed for environment monitoring and human activity recognition. When multiple sensors are in use, fusion could be implemented to achieve higher precision and to avoid system level fail due to fail of single sensor(s) [26]. There is also research in wireless sensor network [27], to enable connecting distinct sensors into a net with low-power, small-size solutions. The question left here is how to transfer the information to a robot.

4 Conclusion

We analyzed in this paper the hazards in dense human-robot co-existing scenario, which, with the fast development and population growth of service robots, will come in the future sooner or later. We gave our hypotheses on the hazards and perform a survey on existing techniques in the research field named Ubiquitous Computing, which could help minimize the hazards. This paper is supposed to serve as a starting-point for supporting robotics development with ubiquitous computing.

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