Collision-Detection for RoboCup@Work-Competitions

Sebastian Zug, Martin Seidel, Jonathan Beckhaus, and Nico Winkelsträter

Otto-von-Guericke University, Magdeburg, Germany
{zug,maseidel}@ovgu.de
{beckhaus,winkelst}@st.ovgu.de

Abstract.
The RobotCup@Work league is motivated by industrial scenarios where objects has to be automatically transported between different working positions. During these operations the rules prohibit and penalize collisions of robots with the arena. Human referees distributed around the arena are responsible for identifying occurred collisions and for their annotation. If a robot moves parts of the arena, a collision is obvious. But, a slight contact is hard to recognize, since not all referees do have a permanent line of sight to the robot and distraction, caused by the surrounding, fatigue, or personal perception are human factors that might affect the outcome of a run. A majority vote might smooth the results, but it is an unsatisfactory solution in debatable situations.
We describe the evaluation of a proof-of-concept implementation for a distributed collision detection, based on a network of acceleration sensors. We investigated different configurations - a single device mounted directly on the robot, an instrumented arena and a combination of both approaches. The paper summarizes a first evaluation based on a proof-of-concept implementation.

Keywords: RoboCup, RoboCup@Work, Collision-Detection

1 Introduction

1.1 Motivation

The RoboCup RoboCup@Work league[1] (short @Work) is one of the youngest competition in the RoboCup family. It is inspired by industrial mobile manipulation scenarios comprises separate runs. Each of them addresses different aspects of mapping, navigation, and manipulation capabilities for transporting assembly parts from one working place to another. At the begin of each run the robot receives an automatically generated list of transportation tasks from the refbox[2] [10]. A local planner is responsible to calculate an optimal task execution

[1] RoboCup@Work website: http://www.robocupatwork.org/

[2] The referee-box or shorten refbox is a software controlling robot competitions. Its capabilities varies per competition and reaches from time keeping, task generation, and scoring. https://github.com/robocup-at-work/at_work_central_factory_hub

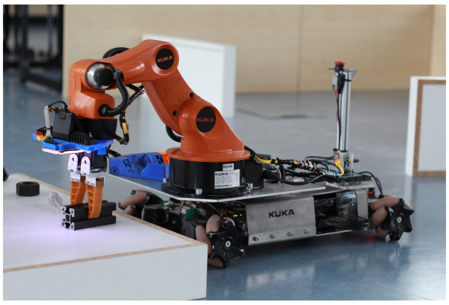

Fig. 1a: @Work robot of the robOTTO team while grasping an object.

Fig. 1b: @Work referees monitoring a run during WorldCup in Leipzig 2016.

sequence and to start its implementation. After reaching the selected working desk, the robot has to recognize the correct objects and to grasp them, as visible in Fig. 1a. Afterwards the robot has to transport and place the objects to the corresponding desk or into an object-specific cavity. From run to run the complexity increases permanently by varying the types and numbers of manipulation objects, additional obstacles, and positions of forbidden areas.

At the end of each run the number of correctly picked and placed objects and the execution time is mapped on a score. Dropping an object or any contact with the environment during the navigation phase [8] generate penalties. Currently, human referees are responsible to detect the occurrence of a collision. During a run, they are distributed around the arena, monitor the competition and log their observations manually. These logs are aggregated and evaluated after the run. Based on our experience, intermediate results would be helpful for teams to decide whether to restart a bad run within the remaining time or to let it continue. Especially for debatable situations this is not implementable without stopping a run's execution followed by a discussion of the referees. But, this procedure would disturb the atmosphere and the attractiveness of the competition. Another reason against the current concept is the number of referees necessary to monitor the whole arena. Many teams complain the required effort, one participant is permanently blocked due to the referee service.

Even in real sport events it is debated to replace impartial referees to some aspects. In [4] for instance the authors showed that the decision can be biased by such simple factors as the colours of the sportswear (blue/red). An automatic referee systems for sport or robotic competitions could guarantee a transparent and objective evaluation as well as an intuitive just-in-time presentation of received information. Correspondingly, most of the leagues already integrate automated referee systems. Especially the teams with a football background apply goal line referees based on vision systems. We therefore propose an on-line collision detection, which is based on an external sensor system that directly interacts with the referee box. This paper describes the challenges and presents a proof-of-concept implementation.

1.2 Scenario analysis

In a first step we summarize our @Work experiences and define a list of assumptions and requirements:

A1. The setup has to cover heterogeneous robots. The @Work League allows participants to design an individual robot system. Most groups use customized Kuka youBots, but, currently founded, new teams started to design their systems from scratch. Hence, we have to develop our collision detection systems that does not rely on any interface (power supply, communication media, assembly points) on the robot.

A2. We have no access on robot's state. We want to receive a high degree of acceptance for our collision detection system. Consequently, it is not intended to define an API which has to be implemented by the teams providing robot data as position, path, velocity information.

A3. The characteristics of the floor is unpredictable. The arena of the @Work league stands directly on the floor. Its material and characteristics vary for each event in general and changes locally caused by a heterogeneous surface as well as by supply shafts and openings too.

A4. People might touch the arena elements while watching the runs. During a run, all participants are next to the arena observing the robot. It is possible that elements are touched or at worst moved in this exciting situation.

A5. The setup of the arena (≈9x6m) is changed at every competition. The structure of the arena is redesigned for each competition. The entire length of the arena elements is approximately 25m in combination with desks of different height and an rotating round table. The needed flexibility limits the applicability of global sensing systems such as tactile sensors. Additionally, the size of the arena makes it difficult to cover the whole setup with only one sensor.

2 Development of a collision detection system

2.1 Definition of an appropriate sensor system

The assumptions A1 to A5 specify the preconditions of a sensing system suitable to recognize contact and collision situations. In contrast to other implementations of automated referee systems embedded in RoboCup competitions (Middle Size League [3], Standard Platform League [9] or Small Size League [12]) we cannot apply common RGB or RGB-D sensor systems. The only (slightly similar) approach is discussed in the Standard Platform League whose organizers intend to detect unsporting behaviour (specific collision of two robots) automatically this year [11]. Based on our assumptions (A5), it is not possible to implement a camera based localization system offering the required spatial resolution for detecting collisions in a large scale, highly dynamic environment as the @Work arena. During the last German Open we had the opportunity to evaluate an OptiTrack system covering the whole arena [3]. The system worked fine as a ref-

[3] Provided by the European Robotics League (ERL)

erence positioning system but it is not able to identify a permitted interaction of a robot and a arena element correctly.

An alternative sensing element are mechanical or tactile sensors [6]. But these sensor types are not applicable for our scenario due to the length of the arena contour (A5) and the unpredictable structure of the robots (A1). All teams mounted laser scanner on the front and backside of the robot. Hence, a spontaneous integration of a bumper system to the robot or a complete coverage of all arena parts by a tactile skin is not possible. Additionally, the occurrence of a sensor ring would change robot's geometry and consequently disturb in path planning and execution algorithms (A1, A2).

Consequently, we evaluated the implementation of an Inertial Measurement Unit (IMU). While evaluating acceleration and rotational speed values, it can be positioned flexibly at the robot. The literature describes the usage of inertial force/torque sensors or accelerometers. Both are used either for mobile robots [7] or in manipulators [1]. As described in the mentioned papers, these sensors demand a complex sensor data processing strategy classifying disturbances and actual collisions in a reliable way [2].

2.2 Experimental setup

Based on this decision we evaluated 3 concepts for mounting the acceleration sensors - an individual one tagged onto the robot, a distributed system of n sensors mounted to the arena and a combined setup exchanging the detection results. The evaluation was done in our laboratory with a robot of the robOTTO team.

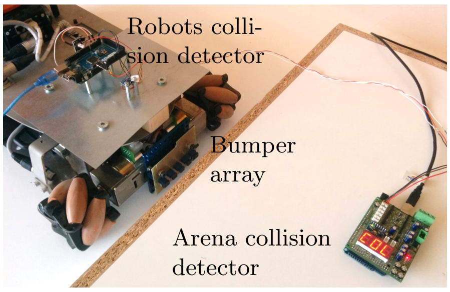

Fig. 2: Experimental setup integrating to accelerometers and a bumper array

We designed a test setup that combines two Arduino Mega ADK equipped with a MPU9250[4] sensor. Fig. 2 depicts the robot on the left side, with an IMU measurement unit mounted on top of it. An array of bumpers in front generated the ground truth signal. The IMU tagged to the arena element is visible in front. All sensor systems were connected to one PC recording all data.

2.3 Robot centric solution

While moving the robot in a straight line to the instrumented arena part we recorded the acceleration values (vector norm of horizontal parts) and the bumper outputs for two different scenarios (collision with an arena segment, free movement and braking till stop) with speeds between 0.1 and 0.7 m/s. Fig. 3 illustrates the bad signal to noise ratio caused by the vibrations of the youBot's

[4] https://www.invensense.com/products/motion-tracking/9-axis/mpu-9250/

omnidirectional wheels. As visible in all diagrams, this effect is correlated with the speed of the robot. For the further development it is remarkable that the peaks, caused by a collision with the table at low speed (upper diagram on the left side), are much smaller than the acceleration amplitude of a free run (lower diagram on the right side). The dashed red line represents the point in time, when one of the bumpers was activated. Each bumper shows a specific immersion depth before it becomes conductive. Consequently, we have to consider a jitter when evaluating the quality of the local collision detectors.

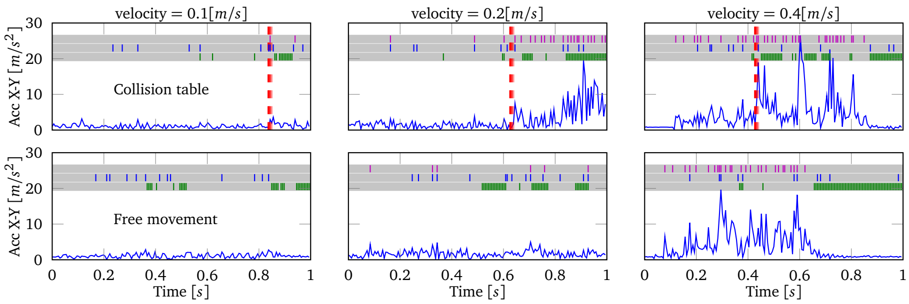

Fig. 3: Acceleration amplitudes for collision and free run situations. The red line shows the occurrence of a collision measured by the bumpers front of the robot

Due to the characteristics of the signal the motion detection capabilities of the MPU 9250 or static threshold for acceleration as described in [5] could not be applied. We implemented three different detection algorithms those results are marked within the gray bars in Fig. 3:

1. a simple gradient base approach comparing the current deviation of the signal with a static threshold ($\Delta acc > 2.0m/s^2$),
2. a statistical evaluation of the quantiles of the last 25 samples related to the actual measurement and
3. a T-test for the means of historic ($n = 100$) and a current sample set ($n = 10$).

The second approach generates a constant number of false positives in each case, while the count of faulty classifications increases for the gradient filter significantly for higher velocities. The T-test provides a reliable but delayed detection result for lower velocities but shows weakness for higher speed levels. It is important to realize, that the evaluation was done off-line. Due to the needed computational performance, the second and the third detection algorithms cannot provide the result within the refresh period of 5ms. A more powerful hardware would help to cope with this problem.

A combination of the first two filters detected all collisions successfully, but generated a huge amount of false positives too. An improved filter mechanism or a fusion of multiple methods would improve the quality of the classification. A conjunction of our filter outputs reduces false positives by half. However, despite all efforts, this output does not fulfil our requirements.

Result 1: *The correct identification of collisions requires a multi-detector strategy. It is difficult to configure these algorithms so that they generates a reliable output for the whole spectrum of velocities.*

Arena centric solution We intend to stabilize the detection quality by additional measurements aggregated at the arena elements. In a first research series we analysed the characteristic pattern of a collision and the stability of these measurements. Fig. 4 shows outputs for collisions with different speeds. The significant change of the signal caused by a collision, enables a precise detection of a collision situation. The IMU includes a digital signal processor called Motion Processor that fuses acceleration and gyroscope data It offers motion detection that can be configured flexibly according to signal amplitudes and patterns. In our case, we defined a acceleration threshold based on a noise analysis of the used sensor.

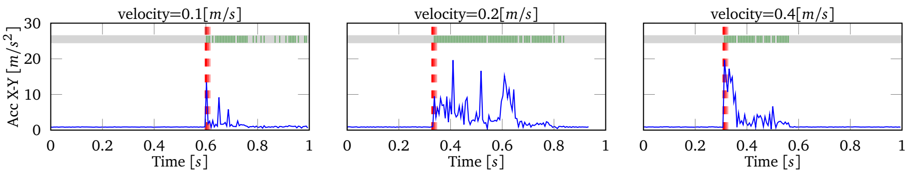

Fig. 4: Acceleration amplitudes measured at the table according to the velocity of the robot

Fig. 4 depicts the outputs for different speed levels. The line illustrates the cumulative acceleration occurring in horizontal direction in case of a collision with the robot. All critical situations were correctly detected, we could not recognise any false positives or false negatives.

Result 2: *The collision detection units integrated in the wall elements are able to identify even slight touches with low velocities. The execution effort is very limited, due to the fact, that the filter is implemented in hardware inside the sensor.*

Combined solution Beside the successful results of the arena centric solution we have to consider probably occurring external disturbances effecting the arena elements (A4). Visitors or participants may disturb the walls or desks during a run. Hence, we intended to combine the collision signals from both origins. This configuration was evaluated off-line due to the demanded computational power for analysing the robot based data sets.

We evaluated unreliable detector outputs from robot signals and filtered them by recognized collisions of the arena sensor. Due to the unreliable output of the robot based detectors we generate a huge amount of fault positives on this side, but still miss collisions for very low velocities. Hence, the validity of the common result was much lower; this result does not justify the additional efforts.

Result 3: *The combined result of the detector output is not suitable to identify external disturbances, especially if the robot touches an arena element with a low velocity* ($< 0.1cm/s$).

3 Evaluation at RoboCup

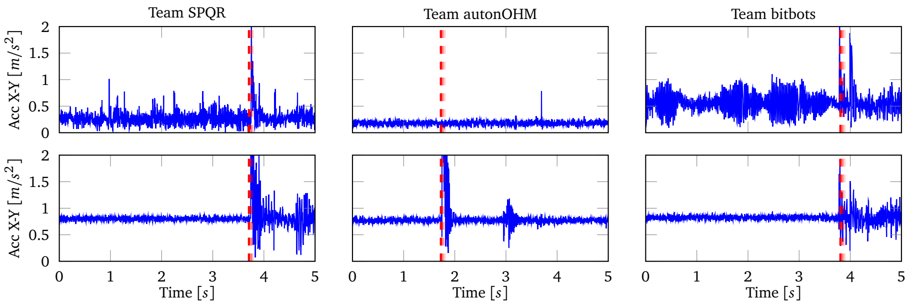

Fig. 5: Exemplary outputs of the IMU measurement units for low speed collisions $0.05m/s$ and $5s$, The upper line depicts the acceleration data from the robots, the lower the measurements from the arena element.

Until now the evaluation was done in the laboratory. During the German Open 2017 we had the opportunity to extend experiments on three other @Work robots. We changed the setup in three points. Firstly, the measurement unit was glued (instead of screwed) on a arbitrary free position on robot's surface. Secondly, the bumper array was replaced by a video system as the ground truth sensor. Lastly, the algorithm implemented for the arena IMU was improved and includes an automated offset calibration and parameter definition now.

During the investigations we focused on velocities smaller than $0.1m/s$; in all other cases the preliminary experiments generated perfect matches. Fig. 5 depicts the new results for three robots hitting the arena element with a speed of $0.05m/s$.

All robots show an individual pattern of acceleration data. Based on their mechanical structure and the assembly point of the IMU, it ranges from a constant noise level (team autonOHM) up to a time correlated oscillation (team bitbots). These measurements confirm our Result 2 and illustrate that it is not possible to find a common filter strategy and an optimal sensor position without a series of preliminary investigations. This cannot be provided during the competition. Consequently, the damping effect in case of team autonOHM avoids a correct detection of the collision (marked by the red line) at all!

In contrast, the reimplementation of the detector provided perfect results from the instrumented arena for all evaluated velocity levels ($0.03m$ and $0.05m$). Besides, we did not receive any side effect by humans or other robots moving close to the arena.

4 Future work

The current proof-of-concept implementation of the instrumented arena hast to be enhanced in different directions. We have to investigate an optimal dissemination of the sensing elements on the arena elements. Additionally, the sensor hardware has to be enhanced by an communication interface (wired / non-wired) and to be integrated into the refbox. A first multiple device test is planned during RoboCup 2017 in Nagoya.

References

1. Cho, C.N., Kim, J.H., Lee, S.D., Song, J.B.: Collision detection and reaction on 7 dof service robot arm using residual observer. Journal of mechanical science and technology 26(4), 1197–1203 (2012)
2. Cho, C.N., Song, J.B.: Collision detection algorithm robust to model uncertainty. International Journal of Control, Automation and Systems 11(4), 776–781 (2013)
3. Dias, A., Almeida, J., Martins, A., Silva, E.: Real-Time Visual Ground-Truth System for Indoor Robotic Applications, pp. 304–313. Springer Berlin Heidelberg, Berlin, Heidelberg (2013)
4. Feltman, R., Elliot, A.J.: The influence of red on perceptions of relative dominance and threat in a competitive context. Journal of Sport and Exercise Psychology 33(2), 308–314 (2011)
5. He, F., Du, Z., Sun, L., Lin, R.: Collision signal processing and response in an autonomous mobile robot. Neural parallel and scientific computations 15(3), 319 (2007)
6. Kerpa, O., Weiss, K., Worn, H.: Development of a flexible tactile sensor system for a humanoid robot. In: Intelligent Robots and Systems, 2003.(IROS 2003). Proceedings. 2003 IEEE/RSJ International Conference on. vol. 1, pp. 1–6. IEEE (2003)
7. Kim, K.S., Llado, T., Sentis, L.: Full-body collision detection and reaction with omnidirectional mobile platforms: a step towards safe human–robot interaction. Autonomous Robots 40(2), 325–341 (2016)
8. Kraetzschmar, G.K., Hochgeschwender, N., Nowak, W., Hegger, F., Schneider, S., Dwiputra, R., Berghofer, J., Bischoff, R.: Robocup@ work: competing for the factory of the future. In: Robot Soccer World Cup. pp. 171–182. Springer (2014)
9. Nezhad, M.S.R., Ghiasvand, O.A.: Ground-truth localisation system for humanoid soccer robots using rgb-d camera. International Journal of Computational Vision and Robotics 7(3), 285–301 (2017)
10. Niemueller, T., Zug, S., Schneider, S., Karras, U.: Knowledge-based instrumentation and control for competitive industry-inspired robotic domains. KI - Künstliche Intelligenz 30(3), 289–299 (2016)
11. Weitzenfeld, A., Biswas, J., Akar, M., Sukvichai, K.: Robocup small-size league: past, present and future. In: Robot Soccer World Cup. pp. 611–623. Springer (2014)
12. Zhu, D., Veloso, M.: Event-based automated refereeing for robot soccer. Autonomous Robots pp. 1–23 (2016)