The ROSIN Project and its Outreach to South Africa

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Abstract: In this paper, we report on the H2020 funded project ROSIN and its outreach activities to South Africa. ROSIN is concerned with developing and maintaining high-quality software components for ROS-Industrial. ROS-Industrial is the industry branch of the Robot Operating System (ROS), a popular open source robot middleware. The ROSIN project is trying to overcome common criticism towards ROS and ROS-Industrial which until recently was preventing larger penetration of industrial applications with ROS. This is done by improving the quality of existing and the availability of new components. Also, educational activities are flanking the ROSIN effort to drastically increase the number of both students and industry professionals trained in ROS. This helps to increase spreading ROS-based application. As an EU project, ROSIN is active across Europe, but especially the education activities are being conducted in Africa as well. The outreach to South Africa is particularly strong here. Many students and industry professionals have already been trained and projects have been funded to advance the state of ROS-Industrial. ROS-Industrial will shape the future of automation and industrial robotics. Proficiency in ROS-Industrial thus is key to leapfrog progress in these fields. With our outreach activities to South Africa we aim to enable brilliant young minds to have part in this development.

Additional keywords: Education, Robot Operating System, ROS-Industrial

1 Introduction

The Robot Operating System (ROS) [1] is around for more than a decade now and it has turned into the standard robot middleware among academics and researchers world-wide. The definition of standard interfaces and providing state-of-the-art software solutions to solve a majority of problems in mobile and industrial robotics such as localization, path planning, or control algorithms makes ROS the most popular platform in robot applications development. It is being used for a diverse and growing range of robot hardware for more than ten years now [2]. ROS provides hardware abstraction and device drivers for a large number of vendors of robot hardware either supported by the ROS community or by the manufacturer itself. In addition, robot application developers can focus on the particular task they want to achieve instead of having to implement side aspects of the application outside of their scope. ROS supports a vast amount of libraries, visualization and debugging tools as well as tools to help newcomers and experts in robotics to quickly get an application up and running by using a package-based software distribution mechanism. What is more to using pre-compiled packages, developers can integrate their custom software locally and deploy it following state-of-the-art best practices in software development. For generalization and reusability, ROS provides definitions of best practices in ROS Enhancement Proposals, which describe key aspects to consider during development in order to allow other developers to re-use the maintained software with standard definitions. In addition, ROS provides ready-to-use tools to perform static code analysis and automated tests in order to maintain high quality software.

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As a branch for industrial applications, ROS-Industrial [3] started in 2013. Despite its success in academia and many efforts, ROS was not too well-accepted by industry for several reasons. Common limitations that ROS critics mention and thus the main barriers for ROS (Industrial) to be used in commercial applications, needed to or still need to be overcome are:

- software quality does not meet industrial standards;
- technical limitations exists (no safety guarantees, no real-time capabilities);
- no certification possible;
- only few ROS-educated people and professionals;
- low interest among European industries in investing in it.

In order to address the aforementioned issues and to foster ROS-Industrial, the ROSIN project was started within the European H2020 programme. An international European consortium consisting of Technical University Delft (consortial leader), Fraunhofer IPA, Germany, FH Aachen University of Applied Sciences, Germany, IT University Copenhagen, Denmark, Spanish research and technology organisation Tecnalia, and Swedish company ABB, started in January 2017 with the ROSIN project.[†] The core idea of the project is to support a ROS-Industrial community effort for developing ROS-Industrial in a way to overcome the mentioned limitations. This is mainly done by kick-starting relevant ROS-Industrial development project of new drivers and components. In so-

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[*] `https://opensource.org/licenses/BSD-3-Clause`
[†] `https://www.rosin-project.eu`

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called Focused Technical Projects (FTPs) professional consortia from industry can apply for funds to start a relevant ROS-Industrial development. Up to 1/3 of the project's development cost (up to a limit of 100,000 €) can be funded by ROSIN. To improve acceptance within industry, the ROSIN project also develops a number of quality assurance measures, tools, and best practices. With measures like continuous integration or code review, the quality of the developed components could be improved. As a final measure to get the Open Source ROS-Industrial middleware better accepted in industry, an intensive education programme was started. Within the project duration of four years, at least 1,000 engineers and students will get training in using ROS for industrial applications.

In the following, we will briefly describe the different activities of ROSIN in the next section (Sect. 2). As the authors are involved with teaching ROS for a long time already [4, 5] and we are also responsible for the ROSIN education activities, we will discuss the different education measures in greater detail. This is also where we reach out beyond Europe, as a number of such teaching activities have taken place in South Africa as well. Section 3 shows the different activities in detail. In section 4 we discuss, what have been achieved so far with respect to education before we discuss how this relates to activities in South Africa in section 5. Finally, we conclude.

2 The ROSIN project

The Robot Operating System has gained much attention in the academic world and it has become a de-facto standard middleware for mobile robotics applications. World-wide, many research institutes make use[‡] of this framework and provide their research work as open-source software modules. To this end, the process to develop a complex robotic application is much easier and less time-consuming today than it was ten years ago. This is because many important components of such a system are readily available as ROS nodes. However, many ROS components do not quite meet the requirements of industrial robotics applications in terms of real-time guarantees or software quality yet. The ROS-Industrial (ROS-I) effort—as mentioned above—was started to deploy ROS also for industrial robots. The benefits are that a larger developer community from different stakeholders can provide software solutions. Further, with ROS-I a form of standardisation of components, sensors and algorithms takes place.

In 2017, funded by the H2020 programme of the European Commission, the ROSIN project was started to support the development and availability of relevant industrial software components in high-quality.

2.1 Overview

The goals of the ROSIN project are to improve on the availability of high-quality intelligent robot software components especially for the European industry. To reach this goal, the criticism brought forward by the industry against ROS, in its current form, has to be addressed. The main points are:

- lack of real-time support;
- stability issues;
- no (software) quality guarantees of the framework and
- a lack of professional training sites.

The ROSIN project's work programme addresses much of this criticism with three main focus areas. The first measure of the ROSIN project is to fund so-called Focused Technical Projects (cf. section 2.2). Second, with special tool support and dedicated training, the quality of the software developed in FTPs will be improved (section 2.3). Third, the development and QA measures are flanked with a broad education initiative for current and future ROS-I software engineers (section. 2.4). In the following, we describe these measures in greater detail.

2.2 Focused Technical Projects

The idea of Focused Technical Projects as promoted by the ROS-Industrial Consortium (RIC) is to kick-start relevant and needed ROS-I capabilities. A full member of a RIC can champion a particular project and share the cost and effort with other RIC members who are interested in that particular capability. Under the guidance of the Consortium Manager, the Southwest Research Institute, San Antonio, Texas, USA, a network of interested developers start with the implementation of the component as soon as the funds are in place. The idea of FTPs is the fundamental concept to support developments within the ROSIN project. With funds allocated by the European Commission for ROSIN, the funding for FTPs is in place. Members of the ROSIN project board decide which projects should be funded. It further monitors the progress of respective FTPs. The challenging goal of the ROSIN project is to give out funds for 50 successful FTPs over the project's time span of four years. As of November 2019, over 45 projects were running and a last round of FTPs was accepted. Results of these projects can be found on `rosin-project.eu/results`.

2.3 Quality Assurance Aspects

The ROSIN project proposal mentions three strategies for how software quality of the newly established ROS-I components could be improved. The quality assurance strategy includes a *community-based quality management process*. It needs to be established in such a way that it proposes quality standards which may or may not be obeyed, but it will force software developers to comply with the given quality standard. There will also be workshops and tutorials as well as some technical support. Within the ROSIN project, a *Continuous Integration Infrastructure* will be provided allowing code reviews, error reporting and unit tests. Further, ROS-specific bug and quality trackers are being developed within the ROSIN project. Also the ROSIN project aims at making quality visible by providing quality measures (such as the current build status as reported by the ROS build-farm) represented on the individual ROS Wiki pages.[§] The *model-driven development* has been identified as a successful design and software production methodology. While there exist some description languages

[‡] `https://metrics.ros.org/`

[§] `https://wiki.ros.org`

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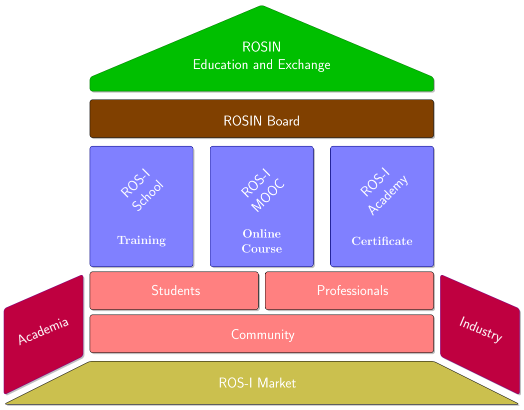

Figure 1 ROSIN Education and Exchange Activities

such as URDF in ROS already, the concept of model-driven code generation will be strengthened to provide another means to assure the software quality. The component testing will also be improved including thorough testing of the ROS core. Besides test-based validation methods, also program-analysis based validation and regression methods is applied to the developed ROS-I components.

2.4 Education

Even when a company agrees to use ROS-I as the middleware for their software developments, a major question remains, namely where to hire employees with fundamental ROS-I knowledge. Despite the fact that many roboticists leaving varsity these days have been in contact with ROS before, profound and certified knowledge is desirable from a company's viewpoint. Therefore, a third pillar of the ROSIN concept is an education and training programme to impart in-depth knowledge of ROS-Industrial. The different ROSIN education measures, which will be described in section 3 in more detail, will convey the required ROS-I knowledge, needed by the industry. The project comes with a number of measures, but is open to further educational ideas. Therefore, it is also possible to apply for funds to run additional ROS-I education measures.

2.5 Discussion

The results of these measures are three-fold. For one, ROSIN increases the number of ROS-I industrial robot components and will gain a wider acceptance in the industry for ROS-Industrial. This is also achieved by the second measure, the QA aspects. As this was a main issue of criticism, with establishing best practices such as code review and tools such as bug trackers, in the ROS-I community we will raise awareness for designing better quality code in this open source community. Finally, teaching students and professionals the basics of ROS and giving a large number of interested individuals easy entry into the ROS world will also extend the number of potential users and serve the industry demands for well-trained ROS engineers. Already, we see an increase in the number of job posts and intern requests on ROS discourse, the main community dissemination channel for such posts.[¶] Figure 1 shows an overview of the different teaching activities that will be described in detail in the next section.

[¶]https://discourse.ros.org

3 ROSIN Education Activities

The ROSIN education activities build on two main pillars, the education of university students and the training of industry professionals in ROS. In a series of so-called ROS-I Schools, university students learn the basics of ROS and ROS 2, mostly focussed on mobile robots. The so-called ROS-I Academies focus on professional trainings which are rather targeting industrial-related topics such as designing pick-and-place applications with light-weight robot manipulators. Massive Online Open Courses (MOOCs) allow both students and professionals to educate themselves and prepare for or follow up on one of the ROSIN courses. As an additional action, there are education activities committed to training future trainers in order to establish new training centres across Europe. This way, a multiplier effect can be achieved. The community is a central part of any open source project. Hence, ROSIN reaches out to foster this community exchange in the ROS-I market. A schematic overview of the different education activities can be found in figure 1. As a final measure, similar to the Focused Technical Projects mentioned earlier, the ROSIN project also gives out financial grants to support educational work such as novel teaching materials or even for setting up new training centres. We will detail these so-called education projects (EP) in section 3.3. Finally, we also speak about our trainer education in section 3.4. The education activities have been previously described in [6].

3.1 ROS-I School

International academics, reaching from undergraduate to post-doc coming from different disciplines, show a high interest in learning fundamental aspects of robotics using ROS. The ROS-I School teaches practical basics of ROS starting with the general concepts of ROS Filesystem structure and the communication principles of ROS. After these fundamentals, the participants learn about transformations in ROS, robot description, simulation, vision, localization and navigation in either five-day or ten-day courses. The ten-day courses allow the participants to further explore the learned aspects and get a more in-depth and hands-on experience.

Each learned aspect is explained in a form of lecture first, before the newly gained knowledge will be deepened afterwards in practical hands-on sessions. There, participants practice how to move from theory to real robot systems. After the participants learned how to realise what they learned in theory they are required to consolidate the content covered by creating a working robotic application.

3.2 ROS-I Academy

The ROS-I Academies in the ROSIN project aim at establishing a certified engineering programme serving ROS-I trainings for industry professionals. The five-day courses cover knowledge on using common software solutions in ROS to perform industry grade tasks such as manipulation including pick & place applications or perform autonomous navigation

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with AGVs. Each of the schooling activities aims at guiding the attendees from the basics of the particular robotics environment (such as using kinematic transformation calculations in ROS or handling common ways of the definition of the robotic environment, for instance, a workcell with a robot arm and a camera attached observing the working area). After knowing the environmental aspects the attendees learn how to equip a robotic system with the capabilities needed and finally how to compose these capabilities to an application. For a manipulation task, for example, this can be to detect an object with common ROS interfaces (such as the Object Recognition Kitchen - ORK[‖]) and afterwards handle the object with a gripper attached to a robot arm. Using the benefits of ROS the actual hardware used is basically independent of the actual application. Ideally, a manipulation application can take place with any manipulator because what the attendees learn are the software concepts of ROS. However, experience has shown that using proper industrial manipulators convinces the attendees that the software used in the training actually works.

One of the challenges that we have to face with our education programme is that the audience can be very diverse. In ROS-I Schools, on the one hand, there are students who have long-standing experience in programming robots, for instance, because they have a RoboCup background, on the other hand, there are other students who barely have experiences with Linux. Likewise, participants of the ROS-I Academies range from ROS experts with deep knowledge in robotics to novices who want to learn their first steps in ROS.

To cater for the different target groups, we developed a curriculum for different prerequisite participant levels. We developed the so-called education cube shown in figure 2 in order to be able to provide an appropriate learning experience for differently skilled target groups and contents.

The idea is to have different topics that will be used for the training on the x axis of the cube in figure 2. On the y axis the particular topic is offered for different prerequisite levels of the attendees. Finally, on the z, there are the different schooling activities. The different contents for a ROS-I School differs from a ROS-I Acadamy, for instance, as we focus more on the theoretical background of robotics in ROS-Schools. The theory might not be that interesting for practitioners.

3.3 Education Projects

Similar to Focused Technical Projects mentioned in Section 2.2, the ROSIN project provides additional funds to support third parties to engage in ROS-Industrial training activities. In total, an amount of 300.000 € is made available for so-called Education Projects (EPs). Every ROS-I community member who can prove her expertise in ROS, ROS-I and education is eligible. Eligible parties can apply at any time. There are three cut-off days during a year where applications are evaluated by ROSIN board members.

The ROSIN project funds three different activities:

1. Setting up training centres funded with up to 30,000 €,
2. Software development to support ROSIN training with up to 15,000 €,

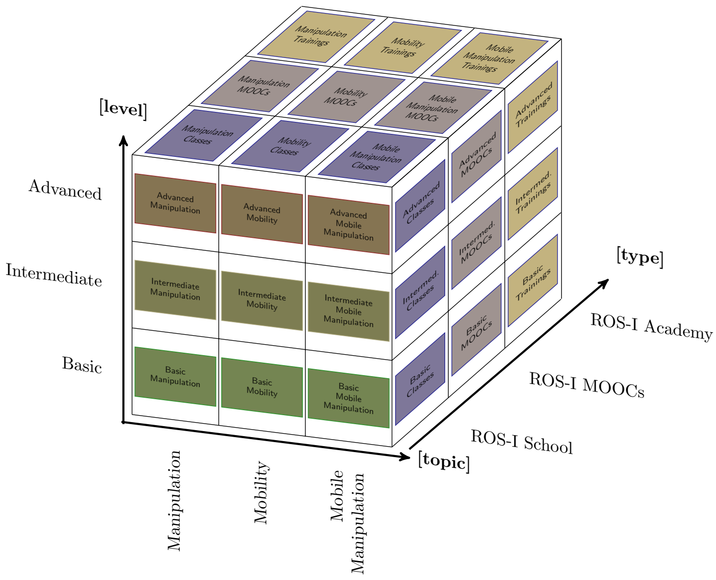

Figure 2 The ROSIN education concept

3. Generation/Improvement of training material (tutorials/slides) with up to 2,500 €.

Applicants can freely chose, which activity they want to conduct. Of course, also a combination of all three is possible. With the first initiative, we want to establish training centres in areas where there is additional ROS-I education demand; the second aims at developing software tools which can be used in education activities; with the third category applicants can get funding for generating new or improving existing training materials. We kick-start these education activities by providing teaching material and we require to receive feedback in order to continuously improve that very material. All participants further agree that the results of their work will be published such that the ROS-I community can benefit from the EP. More information about the education programmes can be found at the ROSIN project website.[**]

3.4 Train the Trainers

In addition to teaching robotics to academics or industry professionals who are experts in their fields but unaware of ROS, the ROS-I Education activities also aim at providing training for ROS experts who are unaware of how to properly introduce ROS to newcomers. The main restriction here is that the attendees of ROS-I Train the Trainers are already aware of ROS. Instead the discussions are composed of common pitfalls for trainers and experiences, and lessons learned during previous ROS-I training hosted.

This also involves inverted training—as the ROS experts learn about performing a training, they can also share their expertise in their respective fields and give feedback and improve on the contents used for the education activities.

4 Achievements of the ROSIN Education Activities

The goals of ROSIN education activities are the following:

- train 1000 individuals during the project run-time;

[‖] https://wg-perception.github.io/object_recognition_core/

[**] https://www.rosin-project.eu/education

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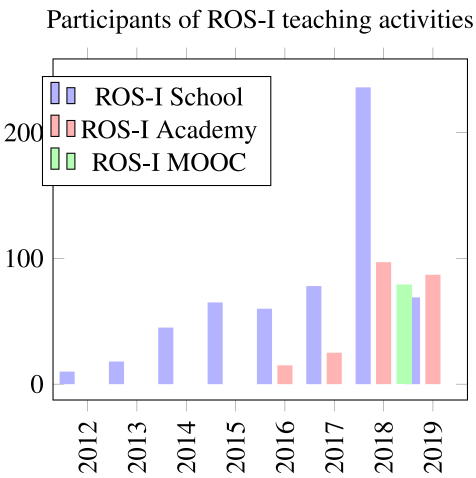

Figure 3 Overview of number of participants trained in the ROSIN context of ROS-I teaching activities.

- provide MOOCs for online training;
- host 2 ROS-I schools per year;
- host ROS-I Academies bimonthly;
- train future ROS educational instructors.

With 12 months of the ROSIN project to go, 507 persons have been trained by ROS-I Schools and ROS-I Academies so far. This number consists of 174 professionals trained at ROS-I Academies and 233 students/professionals who have been trained in ROS-I Schools. Additionally, 100 individuals have been trained in outreach activities outside of Europe. In order to increase the number of trained individuals, more than ten training centres have been funded by ROSIN Education Projects. This will lead to an estimated additional 300 individuals until the end of the ROSIN project. ROS-Industrial education should go on even after the end of the ROSN project. Particular focus is therefore laid on the sustainability of each education measure.

As a final result of ROSIN education activities, the project parters from the Technical University of Delft developed a MOOC named "Hello (Real) World with ROS—Robot Operating System" †† serving a free 6-week online course introducing ROS with an interactive web-based course work. Its first iteration in 2018 had 243 active participants of which 79 completed the course. The next edition will be held in January, 2020.

In total, the ROSIN project aims at hosting eight ROS-I Schools throughout the project run-time. As of today, already 11 ROS-I Schools were successfully conducted. Three of these schools have taken place outside of Europe as part of dissemination actions. Two of the trainers that were trained by the ROSIN partner IPA (Fraunhofer-Institut fÃijr Produktionstechnik und Automatisierung) now already conduct their own training in Venice and London.

Figure 3 gives an overview of the individuals trained at our premises. Already before the ROSIN project, we were active in the field of teaching ROS to university students in the form of Summer Schools. However, since the start of the ROSIN project the number of participants increased dramatically due to the mentioned measures and activities.

5 Outreach to South Africa

Even if South Africa is only the second largest economic system on the african continent, it is the most industrialized country in Africa. The main driving forces for its industrial development are found in the area of natural resources (mining), agriculture (fruit production) and manufacturing (car industry). Other economic fields cover a strong financial market with a vibrant stock exchange and service industry especially in tele communications. The unemployment rate of more than $\sim$27%—being even higher for younger people at around 55%—are one of the major problems in South Africa. It also has one of the highest inequality rates of wealth distribution. The high Gini index (0.63 for South Africa, 0.31 for Germany) are not leading to proper growth and wellbeing of its citizens ‡‡. Connected to the wellbeing, a "brain drain"—the emigration of skilled professionals—is recognized since the mid 90s.

Considering this situation, a modern education based on affordable or even free hard- or software technologies with Open Source projects could incubate new types of start-ups and entrepreneurs. Especially with the background of having only very limited investment, when starting an own company in South Africa, using open source software like ROS for establishing a hightech company is fruitful for South African entrepreneurship.

In order to demonstrate the possibility of an Open Source Robotics framework like ROS, the TUT (Tshwane University of Technology) ROS Summer School was initiated in 2015 and since then is supported by the ROSIN project. The TUT is located near Rosslyn, one of the largest car production centres in South Africa. The car manufacturers use, for instance, unmanned ground vehicles (UGV) with a proprietary software core which could be extended by ROS functionalities. The necessary software skills can be learned at TUT, which is now regularly running the ROS Summer School. Connected to the usage of ROS, other Open Source software tools and applications are presented to the students. These students are the next generation of software developers and engineers working e.g. with collaborative or even autonomous robots. After the training they are able to contribute to the industrial environment with current and advanced technologies available free of charge.

In order to allow robotic students to build their own hardware with a restricted budget, the hardware used at the TUT Summer School consists of a low-cost RC crawler providing the necessary chassis with driving motor and steering servo. Open source hardware such as cheap flight controllers from multicopters is used as inertial measurement units (IMUs). The embedded control system is a quite powerful low-cost single board PC based on smartphone CPUs, the Odroid XU4. An additional USB web cam completes the system allowing it to perform tasks such as optical localization via AR tags or object recognition.

A strong commitment to support technology orientated start-ups is found in Cape Town: the Cape Town munici-

†† `https://online-learning.tudelft.nl/courses/hello-real-world-with-ros-robot-operating-systems/`

‡‡ `https://www.worldbank.org/en/country/southafrica/overview`

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pality is supporting start-ups by establishing tech-incubators offering maker spaces and software training for young people. Often these future entrepreneurs are students visiting the tech-incubators in the city centre such as the Bandwidth Barn in Woodstock, Cape Town. Here the possibility of offering robotic training is obvious and already in discussion. But the city of Cape Town even established a tech-incubator in one of the townships nearby: the Khayelitsha Bandwidth Barn. Here, first contacts were generated in order to train learners with disadvantaged backgrounds in robotics and in ROS, in particular. This builds our own previous work in Kayelitsha where we also trained disadvantaged learners in robotics [7, 8].

Using ROS in combination with simulation tools such as Gazebo reduces the cost for robotic education even more: instead of using expensive real hardware (LiDAR systems, IMUs, high-end cameras), students can log into a simulated ROS world powered by Gazebo which is virtually run in a web browser to reduce hardware requirements. This way, everybody interested in learning robotics could use any kind of hardware to make the first steps into ROS. Despite disadvantages caused by financial inequalities, there is a lot of potential in the human resources which should not be left unused.

A direct impact to industrial application is the export of the well-established ROS Summer School to the NMU (Nelson Mandela University) in Port Elizabeth at the Department of Mechanical and Mechatronics Engineering. The Departement is working very closely with the local car manufacturing industry providing high tech solutions, like e.g. autonomous mobile robots. In order to simplify the design of software components for localization, path planning or mapping, the use of Open Source software in products for the automotive industry was considered. Instead of developing custom-made modules and solutions for e.g. SLAM tasks, ROS was chosen. The ROSIN FHA team generated a one week training session in July 2019 at the NMMU training centre to teach the engineers accordingly. The skilled engineers are now able to transfer ROS skills to the next cohort of students and will soon run their own ROS training.

In cooperation with the NMU we hosted a one-day training for a ROS MoveIt Workshop including a general short walkthrough through ROS and its concepts. To overcome organizational and financial issues the course was hosted with simulated hardware which was possible due to the strong integration of ROS with the Gazebo simulator [9]. As a result each participant was able to work with a physics based simulator for a Melfa Robot arm. In addition the operating system (Ubuntu 14.04) was provided on DVDs and can be re-used afterwards. It also allowed an installation of the complete software stack on a local computer. In general, robotics teaching usually requires expensive hardware setups to be used to properly train industry professionals and academics in the particular application.

With the combination of ROS and Gazebo numerous robotics applications (also consisting of multiple simultaneous platforms) can be simulated for free. Some commercial robotics manufacturers (e.g. Universal Robots) also started to provide simulation packages available to be used within the Gazebo simulator. In general ROS-Industrial hosts an organization on the Github website[§§] consolidating a number of ready to use packages for industrial purposes.

As a consequence the use of open source technologies especially in the field of modern robotics can be beneficial for South African educational projects and finally for its industrial development.

6 Conclusions

In this paper, we outlined the H2020 project ROSIN. To support and extend the ROS-Industrial community, ROSIN supports the development of new ROS-Industrial components. The goal is to improve the software quality and to establish quality assurance measures in the developers' community. Finally, these measures are supported by an extensive ROS-Industrial education programme for both, varsity students and industry professionals. As the authors are responsible for the education activities, we focussed on the education activities in this paper. A number of ROS-Industrial education measures have also been conducted in South Africa. With these outreach activities we aim to enable brilliant young minds to have part in the continuing development of automation and industrial robotics. This development will largely be shaped by ROS-Industrial. Thus, proficiency in ROS-Industrial is key to progress in this fields.

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