Preliminary Study on how an Autonomous Robotic System can impact the Crew Time during Plant Cultivation on the Lunar Surface

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The sustainable human and robotic exploration on the Moon, which is described in the Global Exploration Roadmap (GER), foresees the in-situ food production for astronauts in long-duration missions. To achieve this objective the deployment of greenhouses on the lunar surface for plant cultivation is necessary. With this long-term vision, the German Aerospace Center (DLR) EDEN LUNA project introduces a Moon-analogue greenhouse facility which can demonstrate nearly closed-loop bio-regenerative life support systems technology and aims to grow plants to feed the crew. To support and optimize this food production the autonomous robotic system EDEN Versatile End-effector (EVE) is incorporated into the EDEN LUNA greenhouse. EVE is designed to automatize the plant cultivation cycle opening new possibilities for the sustained human presence on the Moon. For example, in a scaled-up scenario with several deployed greenhouses or during initial uncrewed missions with the need of remote operations from the Lunar Gateway in preparation for upcoming crewed missions. EVE operates in a shared-autonomy manner, which means that the operator's initial command triggers the robotic system autonomous operation. The user is focused on the high-level task solution while the low-level task execution is performed using the local intelligence of the robotic system. This is an important feature which directly impacts the workload of astronauts inside the greenhouse. In this preliminary study, existing works describing crew workload for crop cultivation are considered. These plant-growing ground-based test-beds and space-based experiments are analyzed and compared with the automatized scenario presented in this work. This will provide a significant reference for decisions to be made in future lunar missions. The EVE system is currently in development at the DLR Robotic and Mechatronics Center (RMC) in Oberpfaffenhofen. In 2025, it will be integrated to the EDEN LUNA Greenhouse at the DLR Institute of Space Systems in Bremen. Finally, by the beginning of 2026, it will start operations in the ESA/DLR LUNA facility at the European Astronaut Centre (EAC) in Cologne.

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Preliminary Study on how an Autonomous Robotic System can impact the Crew Time during Plant Cultivation on the Lunar Surface

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Abstract

The sustainable human and robotic exploration on the Moon, which is described in the Global Exploration Roadmap (GER), foresees the in-situ food production for astronauts in long-duration missions. To achieve this objective the deployment of greenhouses on the lunar surface for plant cultivation is necessary. With this long-term vision, the German Aerospace Center (DLR) EDEN LUNA project introduces a Moon-analogue greenhouse facility which can demonstrate nearly closed-loop bio-regenerative life support systems technology and aims to grow plants to feed the crew. To support and optimize this food production the autonomous robotic system EDEN Versatile End-effector (EVE) is incorporated into the EDEN LUNA greenhouse. EVE is designed to automatize the plant cultivation cycle opening new possibilities for the sustained human presence on the Moon. For example, in a scaled-up scenario with several deployed greenhouses or during initial uncrewed missions with the need of remote operations from the Lunar Gateway in preparation for upcoming crewed missions. EVE operates in a shared-autonomy manner, which means that the operator's initial command triggers the robotic system autonomous operation. The user is focused on the high-level task solution while the low-level task execution is performed using the local intelligence of the robotic system. This is an important feature which directly impacts the workload of astronauts inside the greenhouse. In this preliminary study, existing works describing crew workload for crop cultivation are considered. These plant-growing ground-based test-beds and space-based experiments are analyzed and compared with the automatized scenario presented in this work. This will provide a significant reference for decisions to be made in future lunar missions. The EVE system is currently in development at the DLR Robotic and Mechatronics Center (RMC) in Oberpfaffenhofen. In 2025, it will be integrated to the EDEN LUNA Greenhouse at the DLR Institute of Space Systems in Bremen. Finally, by the beginning of 2026, it will start operations in the ESA/DLR LUNA facility at the European Astronaut Centre (EAC) in Cologne.
Keywords: Robotics, Shared Autonomy, Crew Time, Lunar Exploration, Plant Cultivation, Sustainability

1. Introduction

The Global Exploration Roadmap (GER) exploration goals [1] foresee the in-situ food production for astronauts in the long duration missions. This enables sustained living and working on the Moon. The use of greenhouses on the lunar surface can reduce logistics costs and provide the necessary nutrients to the crew diet. However, the greenhouse operations rely on crew time and there are several situations where humans are not available for this task. For example, the initial crew-minimal phase when continuous human presence is not expected, the situation when astronauts need to prioritize scientific activities, and the scaled-up scenario with several greenhouses wherein it becomes impractical to allocate the whole crew to operate and maintain all of the agricultural units. Therefore, the autonomous robotic system EDEN Versatile End-effector (EVE) is incorporated into the EDEN LUNA greenhouse to support the plant cultivation activities and to cover the critical situations stated before. This robot-human partnership ensures that the capabilities of both the astronauts and the robot EVE are complemented in a collaborative manner. Instead of aiming for the total replacement of humans, this collaboration respects the positive impact on the crew's mental health caused by horticultural activity.

The potential benefits of the automatization of the plant cultivation tasks is mentioned in a few publications [2][3]. However, we have no indication that the data of automatized systems was ever published for better understanding this contrast between the work of humans and robots. We see several studies (discussed in Section 2) which describe the application of the robots in agriculture on Earth or space analogues with dedicated plant cultivation area operated only by humans. This paper fills this gap and provide a benchmark for future sustainable lunar missions.

The aim of this work is to reinforce the benefits of the use of autonomous robotics in a lunar greenhouse environment comparing it with the crew time in space analogue missions or real space missions. This paper presents:

- The related work on plant cultivation crew work time, robotics in agriculture, and the EDEN LUNA project.
- A short overview of the EVE robotic system.
- The harvesting test carried out by the robot in our laboratory.
- A short discussion about the tests results.
- A conclusion with a look towards the future.

2. Related Work

In this section, we present the related work on crop cultivation crew work time, agricultural robotics, and the EDEN LUNA project.

2.1 Crop Cultivation Crew Workload

In this study, we considered a few experiments carried out in space analogues and in the ISS. The importance of understanding the work time executed by the crew is crucial because crew time is a valuable resource in space. NASA reports that one hour of crew time in space costs about 130,000 US Dollars [4]. This means that every minute costs 2,170 US Dollars. A considerable amount when we think that astronauts should spend this time with scientific experiments rather than maintenance and housekeeping tasks.

We discuss two of the NASA plant cultivation systems which are currently on-board the ISS: The Veggie [5] and the Advanced Plant Habitat (APH) [6]. The recorded crew time for these two systems is related to watering, initiation, photos and harvesting tasks. For Veggie, a total time of 84 minutes in 30 days for a growth area of 0.13 m^2 were spent. This translates to 21.5 min/day/m^2. For APH, we are not aware of a publication of the crew time recordings. However, there is public information about the growth area (0.2 m^2) and the experiment duration (122 days). If we consider that the approximate crew time spent for Veggie is similar to the one for APH, a total of 341 minutes in 122 days is estimated. Therefore, 14 min/day/m^2.

The space analogues we considered in this paper are the Hawaii Space Exploration Analog and Simulation (HI-SEAS), the Mars Desert Research Station (MDRS), the Inflatable Luna/Mars Habitat (ILMAH), the DLR EDEN ISS, and the Russian BIOS 3 experiment. In the HI-SEAS II [7], the daily crew time dedicated to the plants was on average 15.6 min for a growth area of about 0.5 m^2. This means 31.2 min/day/m^2. In this mission, the tasks included were watering, health and temperature checks, plant cultivation activities such as sowing and harvesting, and preventive maintenance and routine operations activities such as systems cleaning and mixing nutrient solution. For the MDRS [8], the daily crew time was about 45 minutes for a growth area of 5 m^2, which means 9 min/day/m^2. The tasks here were similar to HI-SEAS II with the inclusion of additional specific activities to the mission. For the ILMAH mission [3], the crew time per day was approximately 12 minutes for a growth area of 0.5 m^2. This represents 24 min/day/m^2. The activities included in this mission were plant health monitoring, harvesting, manual watering, and plant data collection. For the EDEN ISS [9] [10], the daily crew time was about 143 minutes in a growth area of 12.5 m^2, which establishes a crew time rate of 11.5 min/day/m^2. Among the activities for this mission, we can find plant health monitoring, harvesting, nutrient solution preparation, and water management. Finally, for the BIOS 3 [11] [12] experiment, the daily crew time dedicated to plant care was nearly 600 minutes for a growth area of 37.5 m^2. This translates in 16 min/day/m^2.

Table 1 summarizes the crew time rate for all the missions.

Table 1. Crew Time Rate for different missions.

Mission	Crew time/day (min)	Growth Area (m^2)	Crew time (min/day/m^2)
ISS Veggie	2.8	0.13	21.5
ISS APH	2.8*	0.2	14*
HI-SEAS II	15.6	0.5	31.2
MDRS	45	5	9
ILMAH	12	0.5	24
EDEN ISS	143	12.5	11.5
BIOS 3	600	37.5	16

*Values based on similar experiment on ISS Veggie

2.2 *Robotics in Agriculture*

There are several studies in agricultural robotics which consider the harvesting task in an open field or in large greenhouses [13-35]. The environment where the task is carried out impacts the mobility of the robot. The width of the alleys and the distribution of the plants determine how constrained the site where the robot operates is. Unlike our EVE robotic system, these robotic systems are developed to completely replace human work in the cultivation area. However, the grasping performance of their end-effectors varies from only 30 to 90 % depending on the cultivars and the robot features as shown on Table 2. Strawberries, tomatoes, apples, sweet peppers, kiwi, and cucumbers are a few examples of crops we find in these publications. The robot structures range from wheeled to guided rail solutions and their end-effectors can be grippers, cutters, suction devices or crop specific picking tools.

According to the work from Bac [29], the main performance parameters are cycle time, which is the total time to harvest one cultivar, success rate and damage rate. We considered these parameters to present the comparative performance rate for the robotics systems analyzed. They are summarized on Table 2.

2.3 *EDEN LUNA Project*

The EDEN LUNA greenhouse [36] (Fig. 1) is a ground demonstrator for plant cultivation in extreme environments. It is part of the LUNA Facility [37] which is a joint project between the European Space Agency (ESA) and the German Aerospace Center (DLR). This lunar testbed is located in Cologne, Germany, and has astronaut training, robotic operations and scientific research as its core activities. The greenhouse is attached to the LUNA main hall. There are several other sub-systems operating alongside EVE, such as: the Nutrient Delivery System (NDS) which provides nutrients to the plants; the Atmosphere Management System (AMS) which regulates temperature and humidity inside the greenhouse; the Combined Regenerative Organic food Production (CROP) which recycles human urine into nutrient solution; the Power Control and Distribution System (PCDS) which distributes the power for the different demands of the subsystems; the Data Handling and Control System (DHCS) which guarantees the telemetry/command transmission and reception from/to the subsystems; the Lighting Control System (LCS) which controls the light intensity, spectrum and duration; and the Thermal Control System (ACS) which transfers the heat from the subsystems to the external environment.

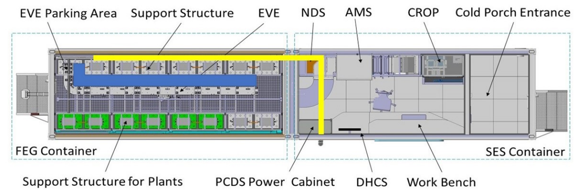

Fig. 1. EDEN LUNA Greenhouse.

3. EDEN Versatile End-Effector

In this section, we briefly introduce the structure and software architecture of EVE [38].

3.1 *Robotic System*

The EVE robotic system (Fig. 2) encompasses a linear rail system, a 7-DOF robotic arm, the CLASH Hand, the camera and an industrial PC. It will be installed on the ceiling of the EDEN LUNA greenhouse.

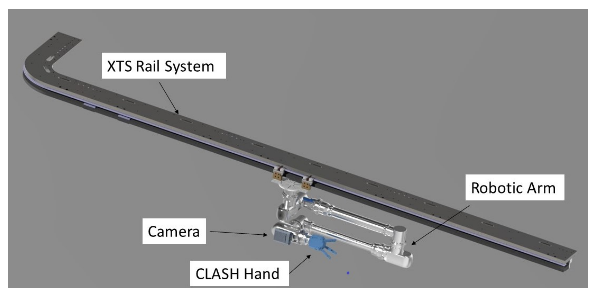

Fig. 2. EVE Robotic System.

The rail system was manufactured by Beckhoff in an L-shaped to allow the robotic arm to be stowed in a parking area when not in use. The robotic arm [39] is part of DLR heritage of low weight manipulators. It has a high degree of manipulability which is perfect for the very constrained space of the EDEN LUNA greenhouse. The CLASH hand [40] can grasp soft objects, such as strawberries or tomatoes, making it very suitable for the harvesting task. It uses its three fingers, palm, and sensors to accomplish the grasping of the target fruit. During the harvesting, the last joint of the robotic arm can rotate to configure the hand with different orientations. This allows the hand to access the fruit from several directions, i.e. top, bottom, front, left, and right. Both RGB and depth images are obtained using an Intel Real Sense camera incorporated with the CLASH hand and are used by a perception algorithm. Finally, the industrial PC, which is also manufactured by Beckhoff, contains the software to control and execute the operation of the whole EVE system in shared autonomy manner.

Table 2. Performance rate agricultural robots.

Robot	Cycle time (s)	Success (%)	Damage (%)	Fail (%)	Crop
Yamamoto [13]	31.5	67.1	12.5	20.4	strawberry
Octinion [14]	3	70	0	30	strawberry
Shiigi [15]	10	38	n/a	62	strawberry
Feng [16]	31.3	86	n/a	14	strawberry
Hayashi [17]	11.5	38	n/a	62	strawberry
Shibuya Seiki [18]	8	54.9	n/a	45.1	strawberry
Xiong [19, 20]	6.1	73.5	n/a	26.5	strawberry
Botian [21]	10	85	5	10	tomato
Kondo [22]	15	50	n/a	50	tomato
Yaguchi [23]	23	60	n/a	40	tomato
Wang [24]	15	86	n/a	14	tomato
Baeten [25]	8	56	24	20	apple
Zhao [26]	15	69.3	7.7	23	apple
Silwal [27]	6	57	27	16	apple
Bulanon [28]	7.1	89	n/a	11	apple
Bac [29, 30]	94	29.5	21	49.5	pepper
Lenhert [31]	35	58	26	16	pepper
Willians [32]	5.5	51	25	24	kiwi
Mu [33]	5	90	5	5	kiwi
VanHenten[34,35]	45	80	n/a	20	cucumber
Average	19.3	64.4	16.2	27.9	n/a

3.2 Shared Autonomy

The shared autonomy concept defines the segregation between what is responsibility of the operator and what is taken care by the robot. The high-level task is kept by the human while the low-level task is driven by the local intelligence of the robot [41]. This means that the user can trigger the operation by an initial command allowing the robot to autonomously execute a sequence of actions to accomplish a task defined by the user.

This architecture is sketched in Fig. 3. A command sequence from the user is dispatched via the command interface block (1). The user's command is received by the state-machine execution block (2). The state-machine execution is organized in a hierarchical manner, allowing sets and subsets of state machines to be arranged depending on the selected task. For instance, the harvesting task can be broken down into several robotic skills such as drive mover, move arm, identify object, and grasp object. This block is linked to the motion planner (3), the world model (4) and the controller (6). The software orchestrates all the blocks to provide autonomous execution of the EVE system. The whole operation is monitored by the user with the communication channels (10) and the telemetry data received on the GUI (11).

4. Robotics Harvesting Test

While the other components of EVE and the EDEN LUNA greenhouse are still in development, we have exe-

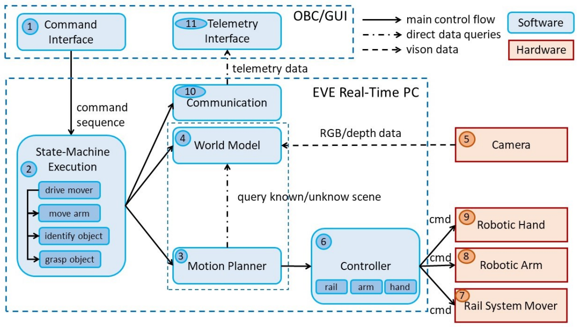

Fig. 3. Software Architecture for Autonomous operation [38].

cuted a preliminary harvesting test in our laboratory. This initial test enables the demonstration of the robotic system capabilities and the challenges foreseen in the actual target environment.

4.1 The Setup

The test setup consists of the tomato plant, the mounting table which simulates the greenhouse's shelf tray, the robotic arm LWR KUKA, the CLASH hand, and the camera Intel Real Sense as shown in Fig. 4. In this setup the orientation of the arm and hand is upside down when compared to the ultimate system design, where the rail system is installed on the ceiling of the greenhouse container. However, for the perception algorithm this reversed orientation does not affect its performance. The shelf tray where the plant is located has the same dimensions (1.35 m x 0.58 m) as in the final EDEN LUNA setup. The tray can fit three tomato plants which have six tomatoes each.

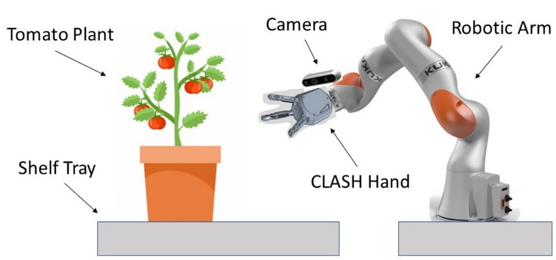

Fig. 4. CLASH Hand setup for harvesting test.

4.2 Methodology

All of the tomatoes are harvested sequentially and a total of 36 trials is performed. This number of trials correlates to six tomato plants distributed in two trays as is anticipated to be the situation inside of the EDEN LUNA greenhouse. The approach of the hand to the target fruit also varies in its orientation. During the test we rotated the last joint of the arm (connected to the base of the hand) around its axis with 0, 30, 45, 60, and 90 degrees. This allowed the hand to approach the target fruit in different directions which have impacted the grasping performance. In the future, we would like to implement the decision of the hand's orientation to the grasping planning algorithm. Therefore, depending on the position of the target fruit, the hand can have an adequate grasp and optimize the grasping success rate. The performance parameters tracked follow the work from Bac [29]. For this study, we simplified them to only three which we consider relevant to the workload characterization. They are cycle time, success rate and damage rate. However, we replace the damage rate, which is considered in the agricultural robots' experiments, with the drop rate. The damage to the skin of the fruit in our test is not measurable, because we use artificial tomatoes in this preliminary study.

The cycle time, which was defined in Subsection 2.2, includes the identification of the target, the grasping, and the transportation of the tomato to the basket. The success rate is the proportion of successful harvesting per total number of trials. The drop rate means that the grasp has occurred successfully, but the fruit has fallen either during the detachment from the branch or during transportation to the basket. The fail rate means that the grasping did not happen correctly, i.e. the hand has missed the fruit position.

4.3 The Harvesting Task

We can describe the harvesting task with three main phases: identification, grasping and transportation. The identification process begins with the capturing of RGB and depth images from the camera to ultimately determine the pose of the CLASH hand. After that, the object bounding is deduced, while distinguishing it from the background which is mainly leaves and branches (Fig. 5). This allows the extraction of the segmentation mask from which the depth of the fruit within the shelf is derived. Then the object position (with respect to the camera) is defined based on the known parameters of the camera. Finally, the position of the object with respect to the robot is provided through a prior robot-to-camera calibration [42]. This relative position calculated by the algorithm is transmitted to the task manager and controller which will act to execute the grasping task. After the grasping is accomplished, the fruit needs to be detached from the branch and transported until the basket. We summarize the grasping sequence on Fig. 6.

4.4 Challenges

A number of challenges were encountered during this test. We describe them as follows.

Fig. 5. Identification of tomatoes on the bush with camera and perception algorithm.

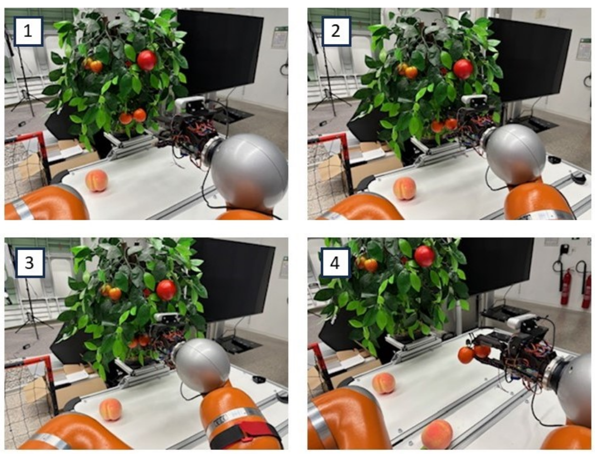

Fig. 6. Sequence of grasping tomato. (1) Target tomato identification. (2) Approaching target tomato. (3) grasping tomato and detaching it. (4) Transporting grasped tomato to basket.

The high agglomeration of leaves and stems create physical and optical obstacles in reaching the fruit. This was already reported in the studies in [13] [29] [31]. We found this same problem when carrying out the test and observed that the position of the leaves in relation to the tomato to be harvest is directly related to the success rate. The more the fruit is blocked the worst is the identification and consequently the grasping.

At this stage of the project, we reused a perception algorithm implemented for a robotic hand which collects random objects inside a box or placed on a table. Although this task seems very similar to the harvesting problem, we have to consider that the contrast provided by the bottom of the box and the top of the table is much higher and facilitates the grasping process. Also, both the box and the table offer a reaction surface which support the object while the hand is grasping it. In the case of the tomato plant, there is no reaction surface. This means that the fruit and the stems can move while the grasp is happening. Therefore, we need to consider this issue to implement adaptations in the second version of the perception algorithm.

Finally, the automatic orientation of the hand is not yet implemented in the perception algorithm. During the test, we have set up the orientation of the hand with respect to the axis of the arm's joint on the base of the hand manually, and then have recorded the results for the different angles. The lack of an automatic selection of the orientation does not allow to approach the target in the most optimal manner. We believe that this is one of the reasons for the high drop rate described on Section 5

5. Results

After carrying out the harvesting tests in our laboratory, we summarize the performance results for the EVE as follows.

5.1 Harvesting Test

In Table 3, we present the results of the harvesting test.

The total of 36 runs is discriminated in five different orientations (0, 30, 45, 60, and 90 degrees) of the CLASH hand with respect to the axis of the arm's joint which is connected to the base of the hand. For the orientation of 0 degree, the cycle time was 20.81 seconds and the success rate 75 %. For 30 degrees, the cycle time was 21.15 seconds and the success rate 50 %. For 45 degrees, the cycle time was 23.47 seconds and the success rate 33.33 %. For 60 degrees, the cycle time was 23.35 seconds and the success rate 57 %. For 90 degrees, the cycle time was 28.51 seconds and the success rate 78 %. The average cycle time for the whole test was 23.46 seconds while the average success rate was 58.3 %.

In Fig. 7, we display these 36 runs with their respective cycle times, performance rate and CLASH hand orientations.

5.2 Crew Work time vs Robotic Work time

To be able to compare the crew work time to the robotic work time, we need to consider the time for the task and the plant cultivation area, so the values are in min/day/m2. The area of the tray is 0.783 m2. Each tray has three bushes, and each bush has six tomatoes. This means 18 tomatoes. The average time for the robot to harvest one tomato is 23 seconds. This is 414 seconds or 6.9 minutes for 18 tomatoes. In addition to this time, we need to consider the time of the mover on the rail (5m @ 5cm/s = 100 s) and the initial movement of the robotic arm (30 s). Therefore, the adjusted time for the harvesting task is 9.07 minutes. When we divide this time for the area (0.783 m2), we obtain the rate 11.58 min/day/m2. This

Table 3. Performance rate EVE.

Orientation (°)	Run	Cycle time (s)	Grasping time (s)	Success (%)	Drop (%)	Fail (%)
0	4	20.81 ±1.27	12.12 ±1.03	75	25	0
30	10	21.15 ±1.43	12.20 ±1.28	50	50	0
45	6	23.47 ±3.30	10.18 ±1.49	33.33	33.33	33.33
60	7	23.35 ±1.11	13.22 ±0.97	57	43	0
90	9	28.51 ±0.99	16.57 ±0.99	78	22	0
Total	36	23.46 ±1.62	12.86 ±1.15	58.30	36.10	5.60

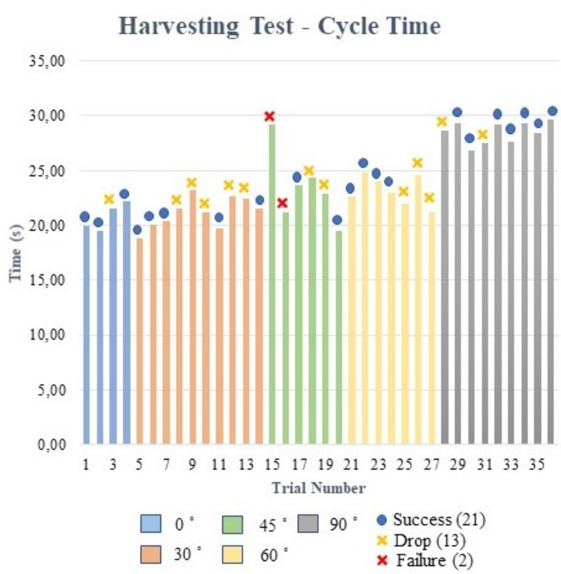

Fig. 7. Harvesting test cycle time chart with different hand orientations and the performance rate.

Table 4. Crew Work time vs Robotic Work time.

Mission	Crew time/day (min)	Growth Area (m^2)	Crew time (min/day/m^2)
ISS Veggie	2.8	0.13	21.5
ISS APH	2.8*	0.2	14*
HI-SEAS II	15.6	0.5	31.2
MDRS	45	5	9
ILMAH	12	0.5	24
EDEN ISS	143	12.5	11.5
BIOS 3	600	37.5	16
EVE	**9.1**	**0.78**	**11.6**

*Values based on similar experiment on ISS Veggie

rate can be compared to the crew time rates which range from 9 to 31.2 min/day/m2. Table 4 indicates the relative work times for Crew and EVE.

6. Discussion

The harvesting test results presented in Section 5.1 show that the CLASH hand can grasp fruits with a performance rate (58.3 %) similar to several existing agricultural robots (64.4 %). Clearly, these results are part of preliminary tests, and several points can be improved until we reach the final stage of the project. While the average cycle time for the harvesting robots is about 19 seconds, we reached an average of 23 seconds. This is a comparable outcome. Since 36 % of the grasps resulted in dropping the fruit before the hand reached the basket, this is a point to be adjusted in the algorithm and can be enhanced during the development of the system. Modifications on the orientation of the hand as it approaches the target tomato are necessary for a more accurate grasping. This is also linked to the perception of leaves and branches. If the perception algorithm can understand the position of the leaves in relation to the target fruit, an adequate orientation of the hand can be set up to avoid imperfections on the execution of the grasping task.

Based on the harvest results presented, we have converted the EVE harvesting data in minutes/day/m2 to allow its comparison with the crew's work time. We noticed that the performance rate of the EVE system (11.6 min/day/m2) is equivalent to the fastest performance rates of the analogue and space missions (9 and 11.5 min/day/m2). This demonstrates that the robot can do the task as efficiently as the crew.

In general, we are satisfied with the preliminary results of the test. This was only the first test in the project and we are very close to the average success rate of the presented harvesting robots. The findings regarding the points of improvement will help us to better develop our system and the perception algorithm to achieve a good performance rate in the final EDEN LUNA setup.

7. Conclusion

In this paper we presented the preliminary tests of our autonomous robotic system EDEN Versatile End-effector (EVE) and how it can impact the crew time during plant cultivation activities in a simulated lunar mission. We believe this is a relevant reference for supporting decisions to be taken in future lunar missions.

First, we introduced the scenario which foresees the in-situ food production and human-robot partnership in future sustainable lunar missions. Then we described the related work on crop cultivation crew work time, agricultural robotics, and the EDEN LUNA project. We also presented a short overview of the EVE and the harvesting test we carried out in our laboratory. Finally, we discussed the results of the test and compared them to existing harvesting robots and the analog missions' crew work time.

In conclusion, the use of robotic systems such as EVE in lunar greenhouses is an important step to achieve sustainability in future missions to the Moon and beyond. This study showed that EVE can be as efficient as the crew in executing the harvesting task. However, we expect improvements until actual operations in the final EDEN LUNA setup. Therefore, we have a promising robotic system to partner with humans in the exploration of our solar system.

The EVE system is currently in development at the DLR Robotic and Mechatronics Center (RMC) in Oberpfaffenhofen. In 2025, it will be integrated to the EDEN LUNA Greenhouse at the DLR Institute of Space Systems in Bremen. Finally, by the beginning of 2026, it will start operations in the ESA/DLR LUNA facility at the European Astronaut Centre (EAC) in Cologne.

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