# Verification of applicability of ABB robots for trans-planting seedlings in greenhouses

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**Abstract**: The article deals with the verification of applicability of different types of ABB industrial robots for trans-planting seedlings. Initial hypothesis was formulated at the beginning namely that the robots with full rotary series and parallel kinematical structure can be employed in the operation of trans-planting seedlings. Testing was performed on real types of robots IRB 1400, IRB 140T and IRB 140B, and using model application. The robot IRB 340 was tested in virtual simulation only. Based on the measurements, it was found out that all real robots tested are able to perform the operation of seedlings trans-planting involving 36 plants with the cycle duration below 2.7 min and at 100% success rate. Within the given range of the movement velocity no statistically significant differences in the cycle duration or in the number of wrongly trans-planted seedlings were found between different robot types. It can be therefore concluded that all the robots tested can be used for trans-planting seedlings.

**Keywords**: robotisation in agriculture; kinematical structures; robots and manipulators; trans-planting seedlings

Trans-planting seedlings of flowers and vegetables in greenhouses can be ranked among the stationary cropping processes. When tomatoes are growing, it is necessary to replant them from the pre-planting containers to bigger silvicultural packets after approximately 15 days. This process is provided by the staff without any mechanisation in the small and middle businesses. The seedlings are taken out by hand together with the ball of soil from the pre-planting containers and then they are planted into bigger silvicultural packets with a dibber. In special growing seedlings businesses (Montano Valtr, s.r.o. and Zahradnictví Lysá nad Labem-Litol), flower-pot machines are used. These machines stream the replant process. They fill in the silvicultural bin with the soil and then dig a hole. The whole process is easier but the manual work is necessary even here because the seedlings have to be put in manually. This paper is aimed at this work.

The fact that Industrial Robots and Manipulators (henceforth IR+M) can be used for this operation has been pointed out by a number of authors. It was already Krutz (1983) who recommended the application of IR+M for trans-planting seedlings, mainly due to the monotonous character of this work.

The research on the development of a robotic transplanter and its components began several years ago. Hwang and Sistler (1986) developed a commercial pepper transplanter using a basic robotic manipulator. Simonton (1991) developed an end-effector for the handling and manipulating of geranium cuttings. He controlled the position, velocity, and force of the end-effector to minimise damage to the petioles and main stem. An end-effector which utilises a rack and pinion mechanism was developed by Kim *et al.* (1995). The end-effector converted the rotational motion of the stepping motor to the clipping motion of the finger.

Kutz *et al.* (1986) dealt with an experiment aimed at the verification of applicability of the PUMA Industrial Robot (henceforth IR) for trans-planting seedlings of tomatoes and marigolds from pre-planting containers with 392 partitions into planting containers with 36 partitions. The objective of this experiment was to define a working cycle of the robot, check its performance, and develop an appropriate end-effector. The verification tests showed that the

Supported by the Ministry of Education, Youth and Sports of the Czech Republic, Project No. MSM 6046070905.

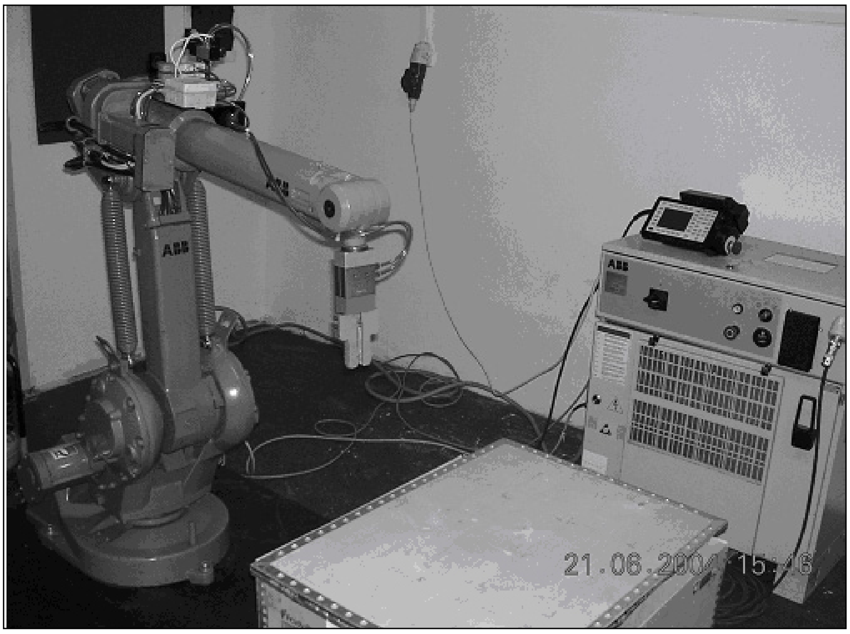

Figure 1. Robot IRB 1400 in experimental place

robot can successfully trans-plant 96% of seedlings, the time for the trans-planting of 36 seedlings into the planting container not exceeding 3.3 min.

Based on the above mentioned, it can be expected that even contemporary IR+M with 6 degrees of freedom (DOF) and a fully rotary kinematical structure can be used for trans-planting seedlings in greenhouses. Monta and Kondo (1999) reported on the application of an industrial robot with 5 DOF and a fully rotary kinematical structure for planting chrysanthemums. The success rate was 90%.

Beam *et al.* (1991) used a machine vision system to inspect the results of seedling transplanting in order to detect unsuccessful operations. Tai *et al.* (1994) developed a machine-vision-assisted robotic transplanting system to improve the quality of the transplanted seedling trays.

The objective of this experiment was to check the applicability of ABB IR's types IRB 1400, IRB 140T, IRB 140B, and IRB 340 for trans-planting tomatoes seedlings (Figure 1). Partial objectives were setting up the work cycle and monitoring the performance and reliability of robots for the given application under changing variables, mainly the operating velocity.

## MATERIAL AND METHOD

The industrial robot types IRB 1400, IRB 140T, IRB 140B, and IRB 340 from ABB firm were used for the automatic cyclical operation of tomatoes seedlings replanting.

The experiment was performed on three experimental stations.

Experimental station A: IRB 1400 with M97A (S4C) control system – manipulator with fully rotary series-type kinematical structure and 6 DOF.

Experimental station B: IRB 140T with M2000 (S4C+) control system – manipulator with fully rotary series-type kinematical structure and 6 DOF.

Experimental station C: IRB 140B with M2004 (IRC5) control system – manipulator with fully rotary series-type kinematical structure and 6 DOF.

Experimental station D (virtual): IRB 340R with M2000 (S4C+) control system –manipulator with fully rotary parallel kinematical structure and 4 DOF.

The experiment was carried out in virtual simulation using Quick Teach programming software.

The pre-planting container had the size or 560 × 280 mm and consisted of 392 partitions 20 × 20 mm each. The planting container with 36 partitions had the identical size as the pre-planting one that is 560 × 280 mm. Instead of real seedlings, wooden sticks were used which were stuck into soft plastic as a substitute for soil bed. For the experiment, three different velocities were defined:

$v_A$ – speed at seedling take-up and planting

$v_B$ – speed during transfer of seedlings

$v_C$ – speed of robot with empty grasper.

The programs for trans-planting seedlings by means of the robots mentioned were generated in the RAPID programming language (operating system BASE WARE) which is used by ABB for programming IRB robots. This language is based to a considerable extent on PASCAL. A detailed description of the program structure and program-

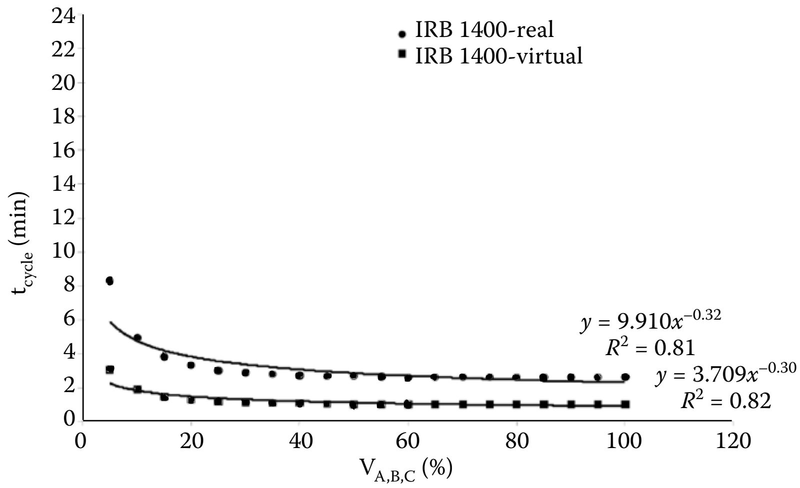


Figure 2. Cycle duration of trans-planting 36 model seedlings plotted against change of speed of PR IRB 1400 using a real robotised system and virtual simulation by means of Quick Teach programming tool

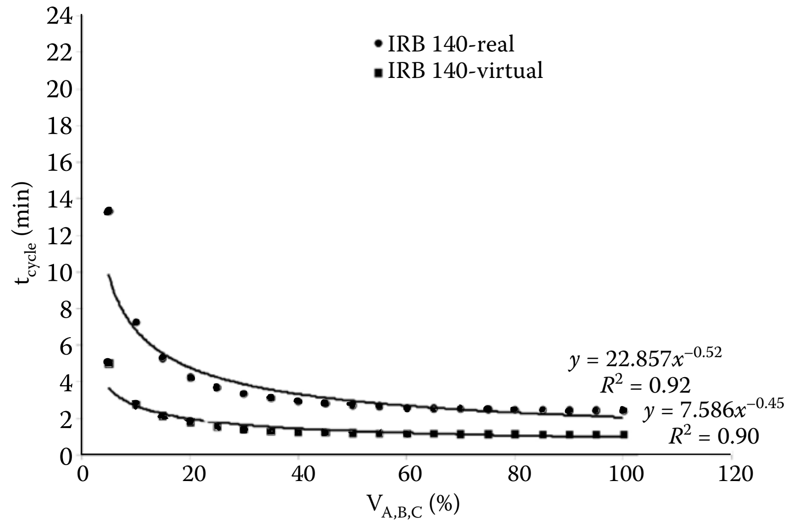


Figure 3. Cycle time of trans-planting 36 model seedlings against change of operating speed of IRB 140T using real robotised system and virtual simulation by means of Quick Teach programming tool

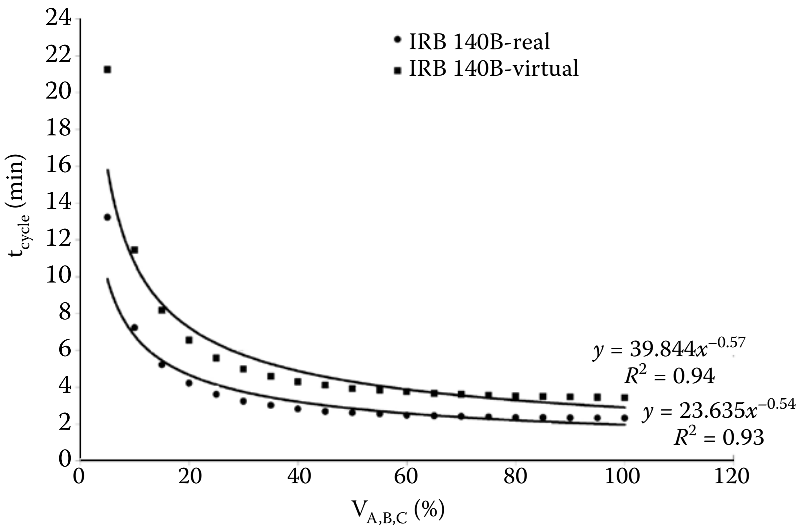


Figure 4. Cycle duration of trans-planting 36 model seedlings against change of operating speed of IRB 140B using real robotised system and virtual simulation by means of virtual IRC5 programming tool

ming instructions including their arguments is given in Rapid Reference Manual (ABB 2004).

Statistical processing of the measured data was performed using the Statistics program. Its outputs are tables and diagrams giving the description of individual measurements. Functionality of MS Excel called Descriptive statistics was used to evaluate the most important selective statistical characteristics.

The design of the work cycle is as follows: Homepos → open gripper head → position above pre-planting container $z_1$ → taking up seedling $n$: move above seedling → dip into soil → grasp seed-

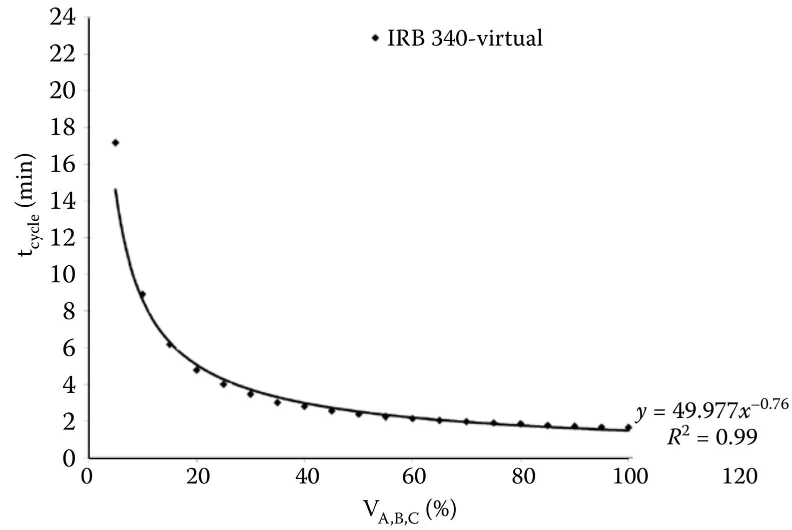


Figure 5. Cycle duration of trans-planting of 36 seedling models against change of operating speed of IRB 340 using virtual simulation by means of Quick Teach programming tool

ling → lift up → position above planting container $z_2$ → planting seedling $n$: move above $p$ → drive into position → release seedling → lift up → position above pre-planting container $z_1$ → Homepos

## RESULTS AND DISCUSSION

The cycle duration of the trans-planting seedling models against the change of the operating speed of individual IR's as well as under virtual simulation by means of Quick Teach programming tool is plotted in Figures 2 to 5. In Figure 5 is given only the virtual simulation.

The objective of the statistical evaluation of the individual data sets is either to confirm or reject the assumption that a change of operating speed setting for trans-planting seedling models on three robots will significantly increase the time of the working

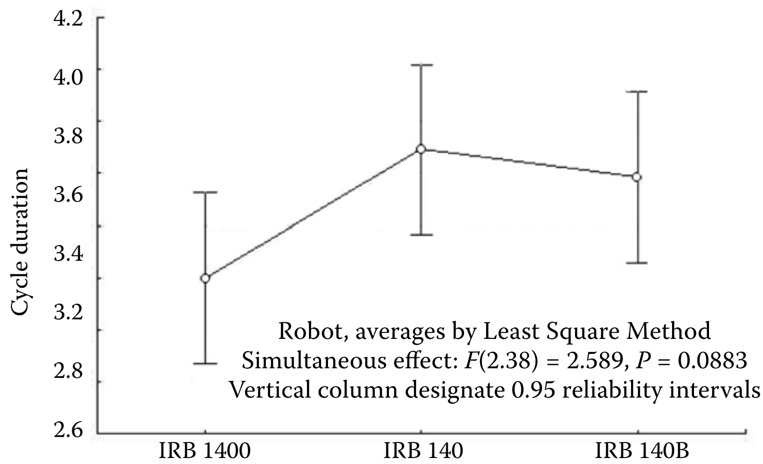


Figure 6. Average values of real cycle duration in minutes for given robot types

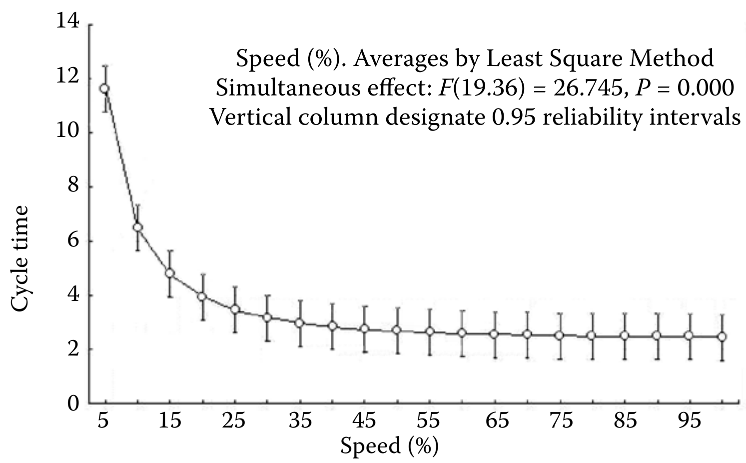


Figure 7. Average real cycle duration in minutes for pre-selected speed

cycle of the trans-planting 36 seedling models. The measurement results of real cycle duration will be subjected to multiple Analysis of Variance to evaluate the relation between the speed and real cycle duration on all three robots.

A prerequisite for the correct application of Analysis of Variance is that the analysed set shows identical data spread pattern. This test is also called check Homogenity of Variance and is performed by Cochran and Bartlett tests. The condition of homogenous dispersion was fulfilled because smaller calculated units *P* for the given set of data were smaller than the surface of relevancy $\alpha = 0.05$.

After the Analysis of Homogenity of Variance, the Analysis of Variance was started. Before the Analysis of Variance, one of the outputs used was the diagram of average values of real cycle duration for the individual robot types (Figure 6) and for the selected individual percentual values of speed (Figure 7).

The calculated *P* value of the speed factor is smaller that the selected significance level $\alpha = 0.05$, which means that statistically significant differences exist between the sets and it is necessary to find out those between which the differences are significant (Table 1). No statistically significant differences of real cycle duration were found between different robot types.

The Statistica program was employed for assessing the significance of differences between the individual speeds. The sets were tested for statistical significance of differences of average, using Multiple Analysis of Variance. The results of the Statistica program is given in the form of an output table with the designation of significant differences (Multiple comparision) (Table 2).

Average cycle duration values designated *x* in the same column do not differ statistically significantly at the significance level $\alpha = 0.05$. In the case of average values with symbol *x* in different columns, the cycle duration values differ significantly.

Table 1. Analysis of Variance for robot type and speed

| | SSq | Degree of freedom | ASq | *F* | *P* |
|---|---|---|---|---|---|
| Speed (%) | 265.53 | 19 | 13.98 | 26.745 | 0.00001 |
| Robot type | 2.71 | 2 | 1.35 | 2.589 | 0.0883 |

SSq – sum of squares; ASq – average of squares, variance; *F* – *F* ratio; *P* – significance level pursuant to value of *F* ratio

Table 2. Classification into classes for given speeds

| Speed (%) | Average of cycle duration (min) | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| 100 | 2.461 | x | | | |
| 95 | 2.467 | x | | | |
| 90 | 2.471 | x | | | |
| 80 | 2.486 | x | | | |
| 85 | 2.487 | x | | | |
| 75 | 2.508 | x | | | |
| 70 | 2.528 | x | | | |
| 65 | 2.552 | x | x | | |
| 60 | 2.583 | x | x | | |
| 55 | 2.628 | x | x | | |
| 50 | 2.675 | x | x | | |
| 45 | 2.733 | x | x | | |
| 40 | 2.833 | x | x | | |
| 35 | 2.972 | x | x | | |
| 30 | 3.167 | x | x | | |
| 25 | 3.454 | x | x | | |
| 20 | 3.937 | x | x | | |
| 15 | 4.794 | | x | x | |
| 10 | 6.480 | | | x | |
| 5 | 11.622 | | | | x |

## Assessing the difference of measurement between real and virtual cycle duration

The objective of was this part has to assess conclusiveness of the difference in the measuring of the cycle duration of a real and virtual cycle for two robot types – for IRB 1400 and IRB 140T. For the third robot this influence was not investigated because it is obvious from the measured values and diagram that the IRB 140 robot shows an error in the IRC5 due to which the cycle duration in virtual simulation was always longer than that of a real robot, which is in contradiction to theoretical assumptions. The presumed cause is an insufficient power of the PC used for the simulation (IBM ThinkPad T40) or the fact that virtual IRC5 software is not a true simulation of reality in the sense of the cycle speed. It would be probably more suitable to use the Robot Studio programming tool which, however, was not available for IRC5.

The assessment was performed using Two-Symple Analysis in the Statistika program. The results are shown in Table 3 where the first line gives the evaluation of the measured cycle duration of real systems,

Table 3. Two-Symple Analysis for robots IRB 1400 and IRB 140

| Robot | Cycle | Average | SD | $N$ | Difference | SD of difference | $t$ | df | $P$ |
|---|---|---|---|---|---|---|---|---|---|
| IRB 1400 | real | 3.20 | 1.33 | | | | | | |
| IRB 1400 | virtual | 1.25 | 0.48 | 20 | 1.95 | 0.85 | 10.28 | 19 | 0 |
| IRB 140T | real | 3.69 | 2.57 | | | | | | |
| IRB 140 | virtual | 1.56 | 0.91 | 20 | 2.13 | 1.65 | 5.77 | 19 | 0.000015 |

$N$ – count; $t$ – T value; df – degree of freedom; $P$ – calculate of significance level; SD – standard deviation

the second line gives the evaluation of the measured cycle duration of virtual systems.

From Table 3 it can be implied that the calculated absolute value $|t|$ = 10.28 for robot IRB 1400 is higher than the table value $t_{0.05, (19)} = 2.093$. For robot IRB 140T, the calculated absolute value $|t|$ = 5.77 was again higher than the table value $t_{0.05, (19)} = 2.093$. Therefore, even here is it not possible to accept the hypothesis $H_0$, but the alternative one about the conclusive difference between the measured duration values of both cycles.

## Measurement of wrongly trans-planted seedlings

The following measured values are the numbers of wrongly trans-planted seedlings with the idividual types of robots and pre-set speeds. In practice, the speed range of approximately 1000 do 4200 mm/s is mostly used. For the robots tested, this corresponds to the speed range of 20% to 55%. Further statistical evaluation will be therefore made for this speed range only (Table 4).

For the statistical evaluation of the offset error, Hypothesis was used concerning the parameters of two alternative distributions (Brabenec *et al.* 2004). Table 5 gives the calculation of the test criterion *u* with the individual robot types. The table indicates that the absolute value of all three values ($u_{12}$, $u_{23}$, $u_{31}$) of the test criterion u is always lower than its table value of the test criterion $u_{0.05} = 1.96$. The investigation performed did not find any statistically significant differences between the numbers of wrongly trans-planted seedlings by all three robots within the given speed range ($u_{12}, u_{23}, u_{31} < u_{0.05}$).

The basic assumption of this paper is that ABB IR's of IRB 1400, IRB 140T, IRB 140B, and IRB 340 type can be used for trans-planting seedlings of tomatoes. The rationale of this thesis is the fact that similar experiments were already performed in the past using universal PR Puma 560, according to Kutz *et al.* (1986). The objective of this project was to validate this thesis practically by both real robots using model applications (IRB 1400, IRB 140T, and IRB 140B), and by the simulation software (Quick Teach and Virtual IRC5).

The robot types IRB 1400, IRB 140T, IRB 140B, and IRB 340 from ABB firm can be used for an automatic cyclical operation of tomatoes seedlings replanting. Using these robots, it takes 3.3 min to replant the seedlings into a silvicultural packet with 36 cells with the efficiency of 96% (the spoiled work is just 4%).

Table 4. Number of wrongly trans-planted seedlings for selected speed range

| Speed (%) | No. of measurements | Wrongly trans-planted seedlings | | | | | |
|---|---|---|---|---|---|---|---|
| | | IRB 1400 | | IRB 140T | | IRB 140B | |
| | | pcs | % | pcs | % | pcs | % |
| 20 | 5 | 13 | 7.22 | 8 | 4.44 | 5 | 2.78 |
| 25 | 5 | 1 | 0.56 | 6 | 3.33 | 0 | 0 |
| 30 | 5 | 0 | 0 | 2 | 1.11 | 15 | 8.33 |
| 35 | 5 | 1 | 0.56 | 0 | 0 | 0 | 0 |
| 40 | 5 | 5 | 2.78 | 0 | 0 | 4 | 2.22 |
| 45 | 5 | 0 | 0 | 7 | 3.89 | 0 | 0 |
| 50 | 5 | 0 | 0 | 6 | 3.33 | 3 | 1.67 |
| 55 | 5 | 0 | 0 | 1 | 0.56 | 0 | 0 |
| Total/average | 40 | 20 | 1.39 | 30 | 2.08 | 27 | 1.88 |

Table 5. Calculation of the test criterion $u$

| IRB 1400 | | IRB 140T | | IRB 140B | |
|---|---|---|---|---|---|
| $m_1$ | 20 | $m_2$ | 30 | $m_3$ | 27 |
| $n_1$ | 1 440 | $n_2$ | 1 440 | $n_3$ | 1440 |
| $p_1$ | 0.014 | $p_2$ | 0.021 | $p_3$ | 0.019 |
| $p_{12}$ = | 0.0174 | $n_{12}$ = | 720 | $u_{12}$ = | –1.4267 |
| $p_{23}$ = | 0.0198 | $n_{23}$ = | 720 | $u_{23}$ = | 0.4014 |
| $p_{31}$ = | 0.0163 | $n_{31}$ = | 720 | $u_{31}$ = | 1.0295 |

In our case, spoiled work means an improper hold of the seedlings due to which the seedlings will drop out from the grab during the process. Another cause is the incorrect placement of the seedling into the appropriate silvicultural packet section (while angular rotation round the vertical axis does not mean incorrect placement). The last one is the seedling gross damage afflieted dduring the replant process.

With the measurements performed, it was found out that all the real robots tested are capable of performing the operation of trans-planting seedlings with a cycle time shorter than 2.7 min at 100% success rate. As compared with the experiments reported by Kutz *at al.* (1986), maximum cycle time under identical conditions was cut down by 0.6 min. and the success rate increased by 4%.

## CONCLUSIONS

It can be concluded that robots IRB 1400, IRB 140T, and IRB 140B can be employed for trans-planting seedlings. In real life, it is also necessary to take into account the character of the environment, mainly its humidity and impurities. For the application in a greenhouse, it is recommendable to use a robot of the protection class IP 67.

Although IRB 340 robot with a parallel kinematical structure was not tested in the real form and the scrap rate was therefore not established, it can be assumed that the success rate above 96% would be achieved at the cycle time below 2 min, the only snag being a relatively small working area which calls for a smaller size of containers or for placing them in horizontal position perpendicularly. When meeting the above mentioned conditions and selecting an appropriate grip head, even the IRB 340 robot can be used for trans-planting seedlings.

***List of symbols***

IR – Industrial Robot
IR+M – Industrial Robots and Manipulators
DOF – Degrees of freedom
ABB – Asea Brown Boveri
IRC – Industrial Robot Controller

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Received for publication May 18, 2006
Accepted after corrections March 10, 2008

**Abstrakt**

Hůla P., Šindelář R., Trinkl A. (2008): **Ověření možnosti použití průmyslových robotů ABB na operaci přesazování sazenic ve sklenících.** Res. Agr. Eng., **54**: 155–162.

Článek je věnován ověření možnosti použití konkrétních typů průmyslových robotů firmy ABB na operaci přesazování sazenic. Na počátku byla stanovena hypotéza, že na operaci přesazování sazenic lze aplikovat roboty s plně rotační sériovou i paralelní kinematickou strukturou. Testování probíhalo na reálných typech IRB 1400, IRB 140T a IRB 140B s využitím modelové aplikace. Robot IRB 340 byl testován pouze ve virtuální simulaci. Na základě provedených měření bylo zjištěno, že všechny testované reálné roboty jsou schopny provádět operaci přesazování sazenic s dobou cyklu nižší než 2,7 min. při 100 % úspěšnosti. Mezi typy robotů nebyly zjištěny statisticky významné rozdíly reálné doby cyklu ani statisticky významné rozdíly mezi počty chybně přesazených sazenic v daném rozsahu rychlosti pohybu. Lze tedy konstatovat, že roboty IRB 1400, IRB 140T, IRB 140B a IRB 340 je možno použít na operaci přesazování sazenic.

**Klíčová slova**: robotizace v zemědělství; kinematické struktury; roboty a manipulátory; přesazování sazenic

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