MAS ISW Reading Reports

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Contents

1 Reading Report: *A review of key techniques of vision-based control for harvesting robot*

(Zhao, Gong, Huang, & Liu, 2016)

Abstract

Although there is a rapid development of agricultural robotic technologies, a lack of access to robust fruit recognition and precision picking capabilities has limited the commercial application of harvesting robots. On the other hand, recent advances in key techniques in vision-based control have improved this situation. These techniques include vision information acquisition strategies, fruit recognition algo- rithms, and eye-hand coordination methods. In a fruit or vegetable harvesting robot, vision control is employed to solve two major problems in detecting objects in tree canopies and picking objects using visual information. This paper presents a review on these key vision control techniques and their poten- tial applications in fruit or vegetable harvesting robots. The challenges and feature trends of applying these vision control techniques in harvesting robots are also described and discussed in the review.

Keywords

Harvesting robot, Vision-based control, Vision information acquisition, Fruit recognition, Eye-hand coordination

Questions

What are the motivations for this work?

- The authors claim that the recognition and the localization of fruits is the biggest bottleneck in harvesting.
- Because of the complex loosely structured nature of the agricultural domain, vision-based control is the only possibility.
- Each fruit hangs or lies in a random location which makes it necessary to continually find the fruits.
- The recognition and localization is the foundation of successful harvesting. So this is the first thing which has to wokr in order to get commercial harvesting robots.
- All in all this papers wants to give an overview over current (2016) techniques to identify fruits in plants.

What is the proposed solution?

- This papers reviews current and older approaches in following categories of vision schemes:
  - Monocular camera scheme
  - Binocular camera scheme
  - Laser active visual scheme
  - Thermal imaging scheme
  - Spectral imaging scheme
- Another part of the review are recognition approaches, those are classified in:
  - Single feature analysis
  - Multi feature analysis
  - Pattern recognition
- The last part of the paper analyses two different ways for the *eye-hand* coordination:
  - Open-loop visual control
  - Visual servo control

What is the work‘s evaluation of the solution?

- Because this work is a review, I will write down and highlight the papers findings in each category:

  Monocular camera scheme

  - This is a classical and cheap approach to recognition. The biggest problem is of course getting 3D coordinates from 2D data.
  - Recognition rates are between 75% (2005) and 96% (2011).

  Binocular camera scheme

  - Using two different calibrated cameras are able to not just get color information but directly create 3D coordinates using triangulation.
  - Recognition rates are also in the 90% area.
  - A system developed 2004 could reliable detect apples with an error of less than 20mm in a distance between 400 and 1500mm.

  Laser active visual scheme

  - By using laser scanners to obtain 3D geometry it is possible to have much higher positional accuracy.

- Different sensors work with different kinds of lasers. By combining different wave lengths it is even possible to detect fruits by spectral reflections.
- Newest data from 2015 shows an accuracy of 97.5% for finding apples with an 3D reconstruction technique.

Thermal imaging scheme

- Infrared radiation from plants can make it easier to distinguish from fruits and other plant parts. Leaves and such accumulate less heats than the fruits.
- Studies in 2008 have shown that citrus fruits are consistent 1 °C warmer than other objects.

Spectral imaging scheme

- Spectral cameras are using special wave length to create more contrast between the fruits and leaves. When looking for green crops this approach can be better than using a traditional camera.
- This technique also got accuracies around 90%.

Single feature analysis

- This way of image-analysis uses only one feature like color, shape, and texture.
- For fruits which have a different color than the other plant parts, using color this a viable approach.
- It is also possible to look for shapes, but this approach has more problems with clusters and occlusions.
- Accuracy's of 95+% are reported.
- This is computational cheaper than using multi-features

Multi feature analysis

- In order to increase detection, reliability and robustness, multiple feautres from an image can be used to detect and localize the fruits.
- Using multiple features increases algorithmic complexity. This needs better processors to compute in an appropriate time.
- Interestingly this review shows *worse* results here, but still in the area of 90%.

Pattern recognition

- The pattern recognition approach uses even more complex algorithms to find the fruits.
- Examples are statistical models, clustering, artificial neural networks, support vector machines and fuzzy patern recognition.
- Here the papers gets worse and worse, no real value besides the pointers to the mentioned papers.

Open-loop visual control

- In an open-loop control mode, the sensors will first detect the positions and then the manipulator will move to estimated positions.
- Without feedback, this system will fail as soon as wind or the manipulators displace the fruits.
- The authors mentioned system where first the manipulators gets placed fast using open-loop control in the vincinity then uses visual servo for fine positioning for grasping the fruits.

Visual servo control

- This mode uses feedback between the manipulator and the sensors to continually adjust the position. This needs a fixed loop between control, computation, manipulators and sensors.
- This approach is slower but also more accurate.
- Generally speaking i think this or a combination of both control modes make the most sense.

What is my analysis of the identified problem, idea and evaluation?

- Vision based system to recognize and localize fruits are needed to make harvesting by robots work. Because the environment is complex and the plants chaotic finding the position of the fruits is really hard.
- The authors describe many ways to exploit some characteristics of the fruits for an easy recognition. But all of those approaches are in my opinion shortcuts which do not really work.
- I think more complex models of the plants are needed to build robots which are able to work in real-world conditions in the industry.
- Of course some of the exploits can help, but the robots must have to work with 3D geometry otherwise the performance will always be worse than the one of humans.
- Occlusion and low contrast have to be part of the models of the robots.
- This will need high computational power.

What are the contributions?

- This review shows some key aspect of the computer vision problems of harvesting.
- The authors created categories of important aspects and showcased work in those.

- The authors **did not** create a systematic approach to compare the results of papers. For example did they show higher accuray for single feature analysis than multi feature analysis or pattern recognition. Which does not make sense.
- The authors also did not say anything about computational costs.

What are the future directions of the research?

- Besides improving the current algorithms and sensor technologies, the authos talked about more coming research in following areas:
  - Human-machine interaction
  - Multi-arm robots
  - Improving Greenhouse environments for robots.

What is my main take away from this paper?

- Current vision systems need to use some kind of exploit or trick to find the fruits. (Tomatoes are redder than the leaves) While this of course an important feature, all approaches lack a model of the plants based on their real 3D geometry. Because of this all robotic systems using those approaches will only be able to pick the best and easiest to see fruits but nothing hidden behind leaves. As long as it is not possible to use a geometry based solution i do not think that robots are viable for agriculture.

Summary

Good pointers to deeper research but no good comparison between papers. No deeper methodology, also not written in a good way.

Rating

2/5

2 Reading Report: *Development of a sweet pepper harvesting robot*

(Arad et al., 2020)

Abstract

This paper presents the development, testing and validation of SWEEPER, a robot for harvesting sweet pepper fruit in greenhouses. The robotic system includes a six degrees of freedom industrial arm equipped with a specially designed end effector, RGB-D camera, high-end computer with graphics processing unit,

programmable logic controllers, other electronic equipment, and a small container to store harvested fruit. All is mounted on a cart that autonomously drives on pipe rails and concrete floor in the end-user environment. The overall operation of the harvesting robot is described along with details of the algorithms for fruit detection and localization, grasp pose estimation, and motion control. The main contributions of this paper are the integrated system design and its validation and extensive field testing in a commercial greenhouse for different varieties and growing conditions. A total of 262 fruits were involved in a 4-week long testing period. The average cycle time to harvest a fruit was 24 s. Logistics took approximately 50% of this time (7.8 s for discharge of fruit and 4.7 s for platform movements). Laboratory experiments have proven that the cycle time can be reduced to 15 s by running the robot manipulator at a higher speed. The harvest success rates were 61% for the best fit crop conditions and 18% in current crop conditions. This reveals the importance of finding the best fit crop conditions and crop varieties for successful robotic harvesting. The SWEEPER robot is the first sweet pepper harvesting robot to demonstrate this kind of performance in a commercial greenhouse.

Keywords

agriculture, computer vision, field test, motion control, real-world conditions, robotics

Questions

What are the motivations for this work?

- Working in greenhouses is a extrem unfriendly environment with boring and repetitive tasks. Finding skilled labor for this get harder and harder every year. Because of this automated and commercially viable automations are needed.
- To make harvesting robots commercially viable it is needed to improve the harvesting performance and speed in real-world conditions.
- This papers shows how one current state-of-art robot performs under realistic conditions.
- Of course the main goal of having robots harvest in greenhouses is cost reduction, quality increase and better predictability.
- Other harvesting robot have cycle times around 33 seconds per fruit. Here the authors want to improve the state-of-art with better results.
- The authors also state, that many research papers lack large-scale experiments, which they want to improve. Maybe they initially wanted to harvest more fruits, but in the end their total harvest was only 262.

- Also most other proposed robot solution are too slow or generally bad to be useable in a commercial way.

What is the proposed solution?

- In this paper the authors propose a robotic harvesting system for sweet peppers and showcase the testing and validations of its capabilities.
- The robots consists of following main components:
  - A standard card driving on rails with a height adjustable platform.
  - Six degree of freedom standard industrial arm
  - Custom build end-effector with a cutter (vibrating knife), sensors and catching mechanism
  - RGB-D camera
  - High-end computer running Ubuntu 14.04 and ROS Indigo with GPU
  - The whole system is really big! The cart is around four times the length of the arm.
- Besides the robot system, the authors also developed algorithms for:
  - Fruit detection
  - Fruit localization
  - Grasp pose estimation
  - Motion control

What is the work‘s evaluation of the solution?

- The authors did a very detailed performance evaluation and error analysis. All in all they did 4 weeks of experiments involving 262 peppers of 2 varieties.
- On average the robot needed **24s to harvest a pepper**.
- So now comes the bad part: Because real-world conditions are extremely demanding, their systems only managed to harvest **18% of the peppers**. To make the robot perform better, they removed leaves and fruit cluster and archived a performance of **61% successful harvested peppers**.
- The main problem with real world conditions are the many occlusions making the detection much harder and often blocking ways of the end-effector to reach the fruits without damaging the plant.
- They also proposed to user a smaller end-effector for easier grepping in a a tight environment for future improvements.

What is my analysis of the identified problem, idea and evaluation?

- The paper, the robot and the analysis of the robots performance are all in-depth and detailed. The robots performance of course is far from being commercial viable.

- During the experiments the authors measured as many parameters manually to get a complete picture of the robots capabilities and shortcomings. (e.g. the paused the robots for each harvesting try to get the relative distance and the angle of the fruits)

- Real-world commercially grown pepper plants have a high density and heaps of leaves hiding the fruits. This results in a complex and unstructured geometry making each of the robot‘s task even harder .

  – The leaves occlude the peppers: The detection and localization needs models which can work with that.

  – Not only the fruits but also the main stem gets harder to detect which is needed to find the relative position of the fruit and steam for cutting.

  – The robot has to navigate around the leaves to cut and catch the fruits: Motion planning gets orders of magnitude more complicated.

- With a modification of the crop the detection and harvest rates got much better. This would strongly imply to make the same robot also removes the leaves. I hope they study this topic as well

- The authors separeted the whole task in several subtasks and delivered an analysis of every one of their problems.

  – Fruit detection

  – Fruit researched

  – Fruit cut

  – Fruit caught

  – Fruit placed into container

- One of my main doubt is that the authors detected the fruit but not the cutting point. That means they positioned the end-effector relative to the fruit and hoped for the best that the knife will find its correct way to cut off the pepper. This method works okay for them, but still this is a area in which they could improve greatly. One of the varieties had longer fruit stems which resulted in a higher failure in the cutting because the knife would slide of.

What are the contributions?

- The authors proposed an integrated system for harvesting sweet peppers.
- Besides that they showcased extensive field testing in a commercial greenhouse with partial real-world conditions.
- The field testing, error analysis, structure of the paper and methodology are also important contributions.

What are the future directions of the research?

- One idea was speeding up the robot. In this experiments with scientists around the robot they could not operate on full speed because of safety concerns.
- Using a smaller end-effector could result in easier motion planning and better navigation in tight, occluded spaces.
- To be able to grep fruits behind leaves it could be feasible to use an arm with an higher degree of freedom. But this would also result in a higher computational cost.
- Some parts of the catching mechanism were too stiff which was a source of repeated failures because it has moved parts of the plants away resulting in positioning errors. For this the authors already have a solution planned for the next experiments.
- As soon as the system looses sight of a specific fruit the harvesting attempt is cancelled. Including some kind of backtracking will result in a improved harvesting rate.

What questions have I left?

- Next to a high-end oc the robot has multiple smaller controllers. I would like to have an in-depth overview over the hardware specs and the components used.
- Could the robot use the same end-effector to remove leaves? If so the robot could in the first step prepare every thing for the harvest itself.

What is my main take away from this paper?

- This paper is quite new so I am a bit disappointed in the performance of the state-of-the-art. Nevertheless the robot platform and paper is sophisticated and I am sure that with a bit tweaking the performance can improve.

- The robots goes to multiple different phases in detection and control modes. Because of this I think the computations are more effecient but on the other hand I seems like it has no proper world and plant model. This results in errors in positioning and the need for occlusion free line of sight to the peppers.
- So the state of the art still relies on simple 2D vision methods for finding its way. This means we need proper ways to model the plants in 3D in an computational effecient form for better motion planning and detection.

Summary

Papers about whole systems with in-depth error and performance analysis are always great. This in particular because it is well written and has a good structure. Comeback to this paper and read some of the references!!

Rating

5/5

3 Reading Report: *Crop design for improved robotic harvesting: A case study of sweet pepper harvesting*

(van Herck, Kurtser, Wittemans, & Edan, 2020)

Abstract

Current harvesting robots have limited performance, due to the unstructured and dynamic nature of both the target crops and their environment. Efforts to date focus on improving sensing and robotic systems. This paper presents a parallel approach, to 'design' the crop and its environment to best fit the robot, similar to robotic integration in industrial robot deployments. A systematic methodology to select and modify the crop 'design' (crop and environ- ment) to improve robotic harvesting is presented. We define crop-dependent robotic features for successful harvesting (e.g., visibility, reachability), from which associated crop features are identified (e.g., crop density, internode length). Methods to influence the crop features are derived (e.g., cultivation practices, climate control) along with a methodo- logical approach to evaluate the proposed designs. A case study of crop 'design' for robotic sweet pepper harvesting is presented, with statistical analyses of influential parameters. Since comparison of the multitude of existing crops and possible modifications is impos- sible due to complexity and time limitations, a sequential field experimental setup is planned. Experiments over three years, 10 cultivars, two climate control conditions, two cultivation techniques and two artificial illumination types were performed. Results showed how modifying the crop effects the crops characteristics influencing robotic har- vesting by increased visibility and reachability. The systematic crop 'design' approach also led to robot design recommendations. The presented 'engineering' the crop 'design' framework highlights the importance of close synergy between crop and robot design achieved by strong collaboration between robotic and agronomy experts resulting in improved robotic harvesting performance.

Keywords

Crop design, Harvesting robot, Sweet pepper, Agricultural robotics, Crop engineering, Robot design

Questions

What are the motivations for this work?

- One of the main factors limiting the performance of robots in agriculture is the unstructured and dynamic environment. To reduce this, the authors created a case study to *engineer* a improved crop-*design* at the example of sweet peppers.
- Similar to using a robot in an industrial environment, a greenhouse should also be optimized towards the robot. Much research works the other way around, but it is important to go both ways.
- The authors want to present a systematic methodology to select and modify crops for an improved harvesting.
- Improved greenhouse and crop design will directly result in a better performance of the used robotic systems.

What is the proposed solution?

- In this study, the authors they describe experiments run during 3 years in a greenhouse in the Netherlands.
- They tested different varieties of sweet peppers and described which conditions are desireable for automatic harvesting and robotic help.
- Overall they authors propose a framework for an engi approach to crop design.
- The authors described following performance indicators which depend in the crop design:
  - Fruit location success

- Detachment success
- Harvest success
- Damage rate

- The proposed methodology also includes following characteristics of the crops:

  Visibility This is the percentage of total fruit area without occlusion

  Reachability The free space around the fruits in which the robot can freely move its manipulator.

  Graspability Measure for the quality of the pose of the fruit. "The grasping point should lie within the part of the fruit that points away from the plant stem."

  Detachability How easy it it for the manipulator to detach the fruit from the plant.

- To modify the crops, the authors propose following methods:

  Selection of suitable varieties The openess and fruit density highly depends on an suitable selected crop

  Cultivation technique This strongly impacts many aspects like the visibility and reachability of the fruit. Here the crops are altered by removing leaves and/or young fruits.

  Climate control

  Temperature The authors suggest that higher temperatures in the mornings result in longer internodes and fruit stemps.

  Humidity Higher realtive humidity should also result in better characteristics: Better internodes and thus easier fruits to harvest mechanically.

  CO_2 **concentration** Higher CO_2 concentration should yield a decrease in leaf surface area and so an improved fruit visibility. Which then results in more harvested fruits.

  Additional growing lights Some research the authors cite, says that an higher amount of blue light could result in more open plants with longer internodes.

- The last category the authors suggested are the crop measures. Those allow to compare the resulting crops in perspective of the robotic harvesting.

  Crop density This a value between 0-100% describing how easy it is to look through the crop.

  Lenth of internodes This describes the lenth of an segment between two leaves. A longer internode usually results in an easier approach for the robot and thus better harvesting.

Position of the fruit on the stem Since fruits hanging towards the robot are easier to harvest, this value describes the axis between the gripper and the fruit to harvest.

Estimation of successfull harvesting This is an estimation based around the space around the fruits.

Production This is calculated based on how many fruits are harvested in $\frac{kg}{m^2}$

What is the work‘s evaluation of the solution?

- The authors manged to create a feasible recommendation for growing sweet peppers in a greenhouse. The recommendation includes varieties of peppers, and a special cultivation method.
- Unfortunately climate control is not showing a positive outcome so this is not recommended because it decreases the yield.
- Using additional grow lights did not yield improvements for the harvestability of the crops here is additional research needed.
- The authors also said that it is important to deepen the research in the choosing of harvesting method.

What is my analysis of the identified problem, idea and evaluation?

- The concrete results are not as impressive as initial thought
- The highly methodic approach resulting from collaboration with domain experts on the other hand is really important and should be noted.
- I really like the approach of engineering a optimal greenhouse and crop design for simplifying the robotic work - I will follow the authors and also deepen my research in this area.

What are the contributions?

- An in-depth methodology for describing and choosing a crop and its environment to grow it in to maximize robotic help in the whole growing process.
- They also have a concrete recommendation on how to culticate red and yellow peppers for optimal robotic conditions.

What are the future directions of the research?

- They will continue to find optimal conditions for peppers and also other crops.
- It is also mentioned to include moving platforms in the next steps,

- Next to improving the greenhouse and crop conditions they want to research the effect of a smaller end-effector for grasping the produce.

What questions have I left?

- The next step would be of course to build peppers and other crop-varieties with optimal characteristics. Would be interesting to follow the breeding and engineering of such species
- For me the exact definition of some of the measurements are not clear. How are exactly is the crop density calculated?

What is my main take away from this paper?

- Engineering crops and greenhouse environments for optimal robotic help is a great idea. This will go hand in hand with designing better robots.
- Robots profit most from plant where the fruits are easy to recognize and grasp. This is measured in the crop density.
- It is also easier for robots to grasp fruits when they hang freely.

Summary

Interesting and detailed case study for which crop characteristics are needed to make robots the live easier. Shocker: Its open crops with free hanging fruits! The proposed methodology is great tough!

Rating

4/5

4 Reading Report: *Heterogeneous Multi-Robot System for Mapping Environmental Variables of Greenhouses*

(Roldán et al., 2016)

Abstract

The productivity of greenhouses highly depends on the environmental conditions of crops, such as temperature and humidity. The control and monitoring might need large sensor networks, and as a consequence, mobile sensory systems might be a more suitable solution. This paper describes the application of a heterogeneous robot team to monitor environmental variables of greenhouses. The multi-robot system includes both ground and aerial vehicles, looking to

provide flexibility and improve performance. The multi-robot sensory system measures the temperature, humidity, luminosity and carbon dioxide concentration in the ground and at different heights. Nevertheless, these measurements can be complemented with other ones (e.g., the concentration of various gases or images of crops) without a considerable effort. Additionally, this work addresses some relevant challenges of multi-robot sensory systems, such as the mission planning and task allocation, the guidance, navigation and control of robots in greenhouses and the coordination among ground and aerial vehicles. This work has an eminently practical approach, and therefore, the system has been extensively tested both in simulations and field experiments.

Keywords

robotics, UGV, UAV, multi-robot, environmental monitoring, sensory system, agriculture, greenhouse

Questions

What are the motivations for this work?

- The crop output of a greenhouse is a result of strongly controlled climate and conditions.
- To keep the conditions of a greenhouse in optimal levels, high definition sensor data is needed. This allows will allow local climate control and product traceability.
- Equipping large-scale greenhouses with sensors to monitor data is so expensive that it is often not possible in a high spatial resolution.
- Instead of having multiple stationary sensors, this paper proposes to use mobile robots equipped with sensors instead.
- For creating a model of the greenhouse the papers proposes using following variables:

  Input Variables
    - Ventilation system
    - Heating system
    - Fogging system
    - Shading screens

  Output variables
    - Air temperature
    - Air humidity
    - Solar radiation
    - (CO_2 concentration) not mentioned in the listing of the paper but used anyways

External disturbances

- External Temperature
- External humidity
- Wind speed
- Wind direction
- Solar radiation
- External CO_2 concentration
- Cover temperature
- Crop temperature
- Soil temperature

- The authors also mentioned several advantages of using wireless sensor networks for monitoring like flexibility, modularity and fault tolerance. But having a mobile platform can be cheaper and even more robust then the stationary sensors. And one could also use the robots for tasks like spraying and harvesting.

What is the proposed solution?

- The solution consists of a two robot system. One four-wheel drive unmanned ground vehicle (UGV) robot and one unmanned ground vehicle (UAV). The UAV sits on top of the ground robot until its needed.
- Both robots are equipped with:
  - 2D-cameras
  - Temperature sensor
  - Humidity sensor
  - Luminosity sensor
  - CO_2 sensor
- The goal of the duo is to drive trough the whole greenhouse using a *back-and-forth* strategy.
- When ever the path is blocked, the UAV starts and continues to monitor the rows. UAV and UGV meet after the blocked row is monitored.
- This allows the UAV to recharge and to be ready for the next blockage.
- Both the UGV and UAV are off-the-shelf commercially available hardware. The UAV uses a RaspberryPie for computation.
- In this paper, they are evaluating the strategic partnership between the two robots, **but the UAV is tele-operated!**

What is the work‘s evaluation of the solution?

- The basic idea is, that the UAV can be deployed whenever the path is blocked for the UGV. A commercial greenhouse has a structured layout of rows so the team can meet up at the next crossing.
- Without the UAV the UGV would have to make a detour resulting in a longer runtime and more battery usage.
- Inside different simulated test environments the system archived a performance uplift between 8% and 23%.

What is my analysis of the identified problem, idea and evaluation?

- The idea main idea is really great and progressive. The concrete implementations are good steps in this direction but lack of real benefits.
- Having multiple robots patrol a greenhouse on a regular basis to get high definition spatial and lower definition temporal data has have many benefits over installing a sensor grid in the same spatial dimension. Moving robots can continually measure values while moving but will measure every given point only once per round trip. Combining this with a couple of stationary sensors could yield in an even better modelling of the local climates.
- The solution from the authors is a little disappointing. On the one hand their evaluation is a result of a simulation and one small real greenhouse. On the other hand, the system is not autonomous. The UAV needs to be tele-operated which is a let down. I hope in future research the UAV can fly by itself.

What are the contributions?

- Build a platform from off-the-shelf hardware for mobile monitoring of temperature, humidity, luminosity and CO_2 concentration.
- The authors contribute a simulation system build in *Unity3D 5.2.1* for simulating the behavior of the dual robot system.
- The robot system consists of a UAV sitting on top the UGV which gets deployed as soon as the way is blocked which happends often in real world greenhouses.
- But they do not provide algorithms for flying the UAV. This is done manually by hand.
- Navigation algorithm for the UGV using SLAM and ACML.

What are the future directions of the research?

- They want to make the UAV fly by itself
- Testing it in real world greenhouses is also scheduled

What questions have I left?

- My main concern is the tele-operated drone. This has to get improved in future work: can a UAV fly properly in a cluttered and narrow environment.
- When having a self-flying drone, would it be better to use the combination of UAV and UGV instead of only using a UAV?
- How precise can one model the local climates from this kind of data? (High spatial and low temporal resolution)

What is my main take away from this paper?

- Great idea to get critical environment data from mobile sensors, but the climate modelling aspect has to be researched even more.
- Heterogeneous robot cooperation is really interesting! I wish to learn more about the task and motion planning involved to get a system like this properly running.
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Summary

UGV transporting a UAV for a spontaneous deployment if the path is blocked - amazing idea! The concrete implementations is a bit disappointing but good written paper anyway.

Rating

3/5

5 Reading Report: *Development of a tomato harvesting robot used in greenhouse*

(Lili, Bo, Jinwei, & Xiaoan, 2017)

Abstract

A tomato harvesting robot was developed in this study, which consisted of a four-wheel independent steering system, a 5-DOF harvesting system, a navigation system, and a binocular stereo vision system. The four-wheel independent steering system was capable of providing a low-speed steering control of the robot based on Ackerman steering geometry. The proportional-integral-derivative (PID) algorithm was used in the laser navigation control system. The Otsu algorithm and the elliptic template method were used for the automatic recognition of ripe tomatoes, and obstacle avoidance strategies were proposed based on the C-space method. The maximum average absolute error between the set angle and the actual angle was about 0.14°, and the maximum standard deviation was about 0.04°. The laser navigation system was able to rapidly and accurately track the path, with the deviation being less than 8 cm. The load bearing capacity of the mechanical arm was about 1.5 kg. The success rate of the binocular vision system in the recognition of ripe tomatoes was 99.3%. When the distance was less than 600 mm, the positioning error was less than 10 mm. The time needed for recognition of ripe tomatoes and pitching was about 15 s per tomato, with a success rate of about 86%. This study provides some insights into the development and application of tomato harvesting robot used in the greenhouse.

Keywords

tomato harvesting robot, four-wheel independent steering, automatic navigation, binocular stereo vision system, obstacle avoidance, greenhouse

Questions

What are the motivations for this work?

- Harvesting tomatoes is a very popular and labour intensive vegetable. The annual production is around 60 million tons.
- Because the labor costs are rising - even in China they are trying to find a autonomous solution which can scale up.
- Tomatoes are very soft and sensitive vegetables so harvesting them is especially complicated.
- The authors name several other research in building this kind of harvesting robots, but those have slow reaction and clumsy movement.
- They want to create a fast system for picking tomatoes in greenhouses

What is the proposed solution?

- A robot system capable of :

  - Automatic navigation
  - Recognition of ripeness
  - Detecting the exact position of the ripe fruits
  - Avoiding obstacles.

- The solution also contains a image recognition algorithm and a picking control method.
- The shown robot has a four-wheel drive with independent steering. The 4 wheels are controlled using and Ackermann steering model.
- It detects tomatoes using a stereo-vision camera with a resolution of 1384×1032px
- The pathfinding is done by using a laser scanner
- To pick the ripe tomatoes, the robot has a 4-DOF mechanical arm with a 1-DOF end-effector
- After picking the tomatoes the robot outs them into a crate on its back.
- The total mass of the robot is 540 kg and it reaches an maximum speed of 3.6 km/h.

What is the work‘s evaluation of the solution?

- The authors evaluated every part of their system:
  - The controlling of the **steering angle** resulted in an average error of 0.14° with a standard deviation of 0.04°.
  - **Path tracking by the navigation system** could track the correct path with a deviation of less than 8cm.
  - They also evaluated how much weight the **mechanical arm** the **end-effector** can carry without loosing precision. When using weights up to 1kg no big deviation is measured. So the mechanical system is fit for its main goal of manipulating tomatoes.
  - Inside the greenhouse the **camera-system** has to detect the tomatoes. Here the authors measured a success rate of over 99.3% in a sample size of 300.
  - The position of the tomatoes got detected correctly with an average positioning error of less than 10mm in a range of 600mm.
  - Finally the **picking rate** of the robot was measured to be 87% in a sample size of 100 tomatoes. The robot needs 15 seconds from recognition to pitching the tomatoes.

What is my analysis of the identified problem, idea and evaluation?

- This paper contains multiple system working together for a common goal. It showcases the steps needed to make the robot drive through a greenhouse and pick tomatoes.
- The error and performance analyses is detailed. Only thing lacking is an in-depth breakdown of the task times. The only time measurement in the paper is the 15 seconds from recognition to picking - but how long does the robot need to pick 100 tomatoes?
- Tomato picking has the advantage that tomatoes are easy to detect via camera. A disadvantage is the soft nature of the fruits.

What are the contributions?

- Algorithm to track the path inside a greenhouse using laser scanner
- Control architecture for the mechanical arm using a collision free A*-algorithm.
- Tomato detection and localisation algorithms using stereo vision
- In-depth error analysis.

What are the future directions of the research?

- Improving the success rate and overall speed.
- Using this system to other crops.

What questions have I left?

- They left out some key metrics like time breakdown and total time needed. So I would like to know if this system is even fast enough for a commercial consideration
- I have not fully understand how the collision free path finding algorithm for the end-effector works, so this is something to study next.
- Currently the robot is only following along the space in between two rows in a greenhouse. It would be great to add additional navigation systems for a a fully automated operation.

What is my main take away from this paper?

- The localisation in a greenhouse for tomatoes works good enough to grap them. I did not expect for this to work that good.
- This paper is a good study of a holistic robot system working in the chaotic environment of a greenhouse.

Summary

This paper is a good study of a holistic robot system working in the chaotic environment of a greenhouse. But some key performance indicator are missing, even some already mentioned in the introduction. In the motivation section of the paper they said that other systems would be too slow but did not deliver they own number. Nevertheless a good study and nice read.

Rating

3/5

6 Reading Report: *Field Test of an Autonomous Cucumber Picking Robot*

(Henten et al., 2003)

Abstract

At the Institute of Agricultural and Environmental Engineering (IMAG B.V.) an autonomous harvesting robot for cucumbers was developed and tested in a greenhouse in autumn 2001. Analysis of the harvest process had revealed that at a 2 ha Dutch production facility four robots are needed to replace the skilled human work force during the peak season. Then assuming a success rate of 100%, a harvest cycle might take at most 10 s per cucumber fruit. In this paper the results of the field test of the harvesting robot are reported and analysed in view of the performance criteria mentioned above. Cucumbers (Cucumis sativus cv. Korinda) were grown in a high-wire cultivation system. In four independent experiments the robot was tested. The average success rate was 74.4%. The majority of failures originated from inaccurate positioning of the end- effector at the stalk of the fruit. It was found to be a great advantage that the system was able to perform several harvest attempts on a single cucumber from different harvest positions of the robot. This improved the success rate considerably. A single successful harvest cycle took 65.2 s per cucumber. Since not all attempts were successful, a cycle time of 124 s per harvested cucumber was measured under practical circumstances. The test confirmed the ability to harvest more than one cucumber using a single set of images which reduced the cycle time of a successful harvest to 56.7 and 53.0 s if two or three cucumbers were harvested. To bridge the gap between the measured performance and the design specifications, future research focuses on improving the success rate, faster hardware and software for image processing and motion planning as well as the reduction of the motion time of the manipulator.

Keywords

Harvesting, Computer Vision, Machine Vision, Stereo Vision, Experiment

Questions

What are the motivations for this work?

- The authors wanted to create a comparable solution to recent advances in harvesting tomatoes and eggplants
- Human labour fir harvesting is a tedious and expensive task.
- Robot labour needs to be able to harvest one cucumber every 10 seconds. This experiment tries to show the current (2001) limitations.
- Inside high-wire greenhouses mobile robots can move along tracks next to the cucumber plants which creates a somehow structured environment.
- This proposed architecture should allow complete autonomous harvesting.

What is the proposed solution?

- Mobile system consisting of a robotic arm having a thermal cutter and a suction cup for cutting and grabbing the cucumbers. One camera for taking two images (768x512px) at different positions to find 3D coordinates.
- They restricted the way to cucumbers could grow so that they are always in a specific range reachable for the robots manipulators.
- Removed leaves before hand to lessen occlusion errors.
- They also removed cucumbers growing too close to each other.
- The systems moves along a rail in 33cm steps. At each step the cameras look for cucumbers and if found and big enough proceed with the harvesting.
- The harvesting does not take additional images. All informations come from the initial 2 pictures. Even if multiple cucumbers are found, the initial information and processing has to be enough.
- Because the range of the system is around 1m, the 33cm step allow up to 3 harvest attempts for each cucumber.

What is the work‘s evaluation of the solution?

- For this experiment the authors took in-depth runtime measurements and error protocols.
- On average the system managed to harvest ca. 75% of a present cucumbers.
- For the whole experiment with multiple attempts and failures, the resulting harvesting time was **124s** per cucumber!!!

- If every first attempt would have been successful, the resulting time would have been **75s** per harvested cucumber.
- Most errors (ca. 36%) came from an misplaced end-effector resulting from poor 3D coordinates.

What is my analysis of the identified problem, idea and evaluation?

- Those experiments (20 years ago) have been one order of magnitude too slow for a commercial application.
- I like the idea of using only one camera, but the extra cost would directly result in a speed up which would basically pay for itself to use a stereo camera.
- The evaluation was very good. The authors managed to create an details overview over the shortcomings.
- Especially the failure categorization is great. This should be an inspiration for similar failure reports for my own experiments.
- I was surprised that the paper was that old.
- 10 seconds runtime for the image analysis will be much faster nowadays.

What are the contributions?

- This paper was a report over an in depth experiment using this harvesting system.
- It sheds light in many failure classes and shows how to make a proper report.
- The robotic system had a bad execution time and accuracy.

What are the future directions of the research?

Harvesting crops in greenhouses will continue to be a key research topic. For this case I hope that the authors managed to increase the execution speeds.

What questions have I left?

- Mainly the comparison to todays systems. For the my next reading report I should find a more recent paper about the same topic.
- If the system can easily exchange the end-effectors, it should be possible to use the mobile platform for all kind of different tasks.

What is my main take away from this paper?

Great structured experiment with a promising setup. Having rails in a greenhouse is not too expensive and solves many navigation problems. I am looking forward to deepen my research in this area. Would it be possible to create a rail grid with multiple robots, cooperating in this task?

Summary

Definitely enjoyed the detailed reporting on different failures and execution times. This paper is an excellent blueprint on how to write a report over an experiment.

Rating

4/5

7 Reading Report: Chapter 56 *Robotics in Agriculture and Forestry* from *Springer Handbook of Robotics*

(Siciliano & Khatib, 2016)

Abstract

Robotics for agriculture and forestry (A&F) represents the ultimate application of one of our society's latest and most advanced innovations to its most ancient and important industries. Over the course of history, mechanization and automation increased crop output several orders of magnitude, enabling a geometric growth in population and an increase in quality of life across the globe. Rapid population growth and rising incomes in developing countries, however, require ever larger amounts of A&F output. This chapter addresses robotics for A&F in the form of case studies where robotics is being success fully applied to solve well-identified problems. With respect to plant crops, the focus is on the in-field or in-farm tasks necessary to guarantee a quality crop and, generally speaking, end at harvest time. In the livestock domain, the focus is on breeding and nurturing, exploiting, harvesting, and slaughtering and processing. The chapter is organized in four main sections. The first one explains the scope, in particular, what aspects of robotics for A&F are dealt with in the chapter. The second one discusses the challenges and opportunities associated with the application of robotics to A&F. The third section is the core of the chapter, presenting twenty case studies that showcase (mostly) mature applications of robotics in various agricultural and forestry domains. The case studies are not meant to be comprehensive but instead to give the reader a general overview of how robotics has been applied to A&F in the last 10 years. The fourth section

concludes the chapter with a discussion on specific improvements to current technology and paths to commercialization.

Keywords

Overview, Case studies, coverage planning, weed control, high precision farming, crop yield estimation, Vehicle formation control, plant probing, leaf removal, harvesting, precision forestry, aerial based precision farming

Questions

What are the motivations for this work?

Optimized Coverage for Arable Farming

- Minimizes soil compaction
- Reduces fuel cost
- Reduces time needed

Weed Control

- Weeds directly reduce yield by competing the crops over light, water and nutrients
- Weed control is needed to stop them from spreading
- Robotic control system offer greater mechanical precision and a reduction in herbicides needed.

High Precision Seeding

- When knowing the exact location of the seeded crops all following robotic operation can use this data
- No further local sensing is needed
- Can also be used as an input for localization

Crop Yield Estimation

- manually gathering the required data is labour- and time-consuming error prone process.
- accurate estimations will help growers in labour demand forecasting.
- Better planning reduces costs by optimizing packing and storage capacity.

Precision Irrigation Conventional irrigation technologies dent to over-watering. This is of course wasteful and also increases leaching of fertilizers.

Tree Fruit Production

- One of the hardest problems of farming because of the complex tree geometry
- Sloped terrain (vineyards)
- Need to sense the branches
- Occlusion of the fruits

Vehicle Formation control Using multiple robots together will increase the capabilities even further. One element of MRS is to control robots in a formation.

Plant Probing

- Automated sample taking will enable large scale experiments.
- It is hard to model deformable objects like plant parts (leaves, stems, flowers, fruits)
- Proper models will enable individual plant part care, sampling, harvesting, predicting, robotized phenotyping

Cucumber Harvesting Automated harvesting can improve efficiency and reduce labour costs. The same system can also be used to cut nonproductive leaves from the plants.

What is the proposed solution?

Optimized Coverage for Arable Farming

- Find the optimal way to move around in complex terrain.
- Introduction of *Optimal coverage planning algorithm*

Weed Control

- A robotic system to drive autonomous over trough the fields.
- machine vision based approach to identify weeds
- precise distribution of herbicides

High Precision Seeding

- a driver-less seeding system with high accuracy localization
- smaller wheels allow driving between ros eliminating soil compaction

Crop Yield Estimation

- A machine vision based system which is able to identify crops
- the system is manually driven through orchards at night and takes pictures with artificial light
- works for vineyards, apple orchards and strawberry ranches.

Precision Irrigation A wireless sensor network monitoring the exact soil conditions.

Tree Fruit Production

- Proposed a family of autonomous orchard vehicles.
- Only uses laser range finders, no gps for keeping the cost low
- Designed in a way to enable faster working human labourers.

Vehicle Formation control

- a control architecture based on a path tracking framework.
- should allow multiple robots to continue to drive in formation even in ruff terrain with poor grip conditions.
- the system uses RTK-GPS with an accuracy of 2cm.
- wireless communications between robots to communicate relative positions

Plant Probing

- System consisting of a robotic arm, time-of-flight camera and a measurement technologies
- image segmentation and model fitting are used to find single leaves from depth informations
- The robot arms first finds position from where it can see the whole plant and then it moves further to enable unobstructed viewing of a single leave.
- After selecting a target leave it will take a probe.

Cucumber Harvesting

- Mobile platform mounted on rails in greenhouses
- Harvesting contains several subproblems, one of them is finding the ripeness of the crops. In this case a target weight is given. Because cucumbers are mostly water it is possible to determine the weight from 3D data.
- The system has a single camera but it is possible to move it around to capture the needed 3D informations.
- After identifying the ripe cucumber, it is cut and moved collision free to a storage crate.

What is the work‘s evaluation of the solution?

Optimized Coverage for Arable Farming

- reduces turns needed ca. 15%
- reduces soil erosion cost ca. 25%
- reduces skipped area cost ca. 81%

Weed Control

- 77% of weeds got precisely eradicated
- reduction in herbicides

High Precision Seeding Not much data given, needs further study.

Crop Yield Estimation The results show that the system works surprisingly well in a different environments.

Precision Irrigation

- reduces the water needed by 75% against conventional watering
- should allow multiple robots to continue to drive in formation even in ruff terrain with poor grip conditions.

Tree Fruit Production The different approaches followed by the original authors showed that they are twice as fast as manual labor.

Vehicle Formation control

- they tested using two robots, where one should follow the other in a defined distance along sloped terrain
- the two robots managed to stay in their path with an accuracy of 15cm

Plant Probing In the summary is no further evaluation. Needs additional study!

Cucumber Harvesting

- The system needs on average 65 seconds to cut one cucumber
- Success rate: ca. 75%

What are the contributions?

Optimized Coverage for Arable Farming Finds Optimal paths for 2D and 3D terrain with soil erosion models.

Weed Control They presented 3 different systems to autonomously kill weeds in different scenarios. The second one (volunteer potatoes in sugar beets) seemed like the best one. Further research here!

High Precision Seeding Complete system which achieves high precision seeding.

Crop Yield Estimation A camera rig for small tractors to gather data, can be further improved in the future.

Precision Irrigation Wireless system for monitoring and control

Tree Fruit Production 3 different autonomous platforms navigating by them selves inside orchards. The system has accumulated 350km driven.

Vehicle Formation control A control architecture for two or more robots to stay in formation.

Plant Probing Stationary system to take leave samples.

Cucumber Harvesting Whole system harvesting cucumbers and cutting leaves. Has algorithm to determine the ripeness and for finding paths for collision free manipulations.

What questions have I left?

Optimized Coverage for Arable Farming What is about the path length and exact fuel reduction?

Weed Control How is it possible to increase the velocity further? The machines are too slow.

High Precision Seeding Concrete implementations for further data fusion of seed map with the next scans for a living yield map.

Crop Yield Estimation Why is the system not self driving?

Precision Irrigation The savings in water needed and increase in growth speed are really impressive. How did this work? Did they somehow cheat on the data? Definitely study the original paper.

Tree Fruit Production Of course using vehicles is faster than manual work using ladders - but are they faster using the same approach with drivers? How does the navigation work with no GPS?

Vehicle Formation control How valid are the results today? Driving two robots in grass does not sound to impressive.

Plant Probing Can this system be mounted on rails?

Cucumber Harvesting How does the accuracy shrink when speeding the process up? How fast can this scale up?

Summary

Summarizes many different papers in-depth. Refer to this for further research.

Rating

5/5

8 Reading Report: *Plant detection and mapping for agricultural robots using a 3D LIDAR sensor*

(Weiss & Biber, 2011)

Abstract

In this article, we discuss the advantages of MEMS based 3D LIDAR sensors over traditional approaches like vision or stereo vision in the domain of agricultural robotics and compare these kinds of sensors with typical 3D sensors used on mobile robots. Further, we present an application for such sensors. This application deals with the detection and segmentation of plants and ground, which is one important prerequisite to perform localization, mapping and navigation for autonomous agricultural robots. We show the discrimination of ground and plants as well as the mapping of the plants. Experiments conducted using the FX6 LIDAR by Nippon Signal were carried out in the simulation environment Gazebo, with artificial maize plants in the laboratory and on a small maize field. Our results show that the tested plants can be reliably detected and segmented from ground, despite the use of the low resolution FX6 sensor. Further, the plants can be localized with high accuracy.

Keywords

Individual plant detection, Plant mapping, 3D LIDAR sensor, Agricultural robotics

Questions

What are the motivations for this work?

A key problem in agricultural robots is to detect and map individual plants for several reasons, including navigation, individual reports and individual care. For a robust plant mapping it is needed to use reliable sensors and algorithms. Much research is done in solving this problem using 2D and 3D cameras but this paper on the other hand, works on detecting plants using low cost and low resolution 3D Lidar sensors.

What is the proposed solution?

The solution contains an algorithm for detecting individual plant in a row using a FX6 3D Lidar sensor. This sensor is still in development, the current version has a resolution of 29 by 59 pixel creating 15 frames per second. To detect the plant from the resulting point cloud, the algorithm first detects the ground plane and second creates cluster for each plants using a k,d tree and decides for each cluster only using the bounding box dimensions.

What is the work‘s evaluation of the solution?

The proposed algorithm works seemingly fast, and manages to identify in a single frame 60% of the plants and using multiple frames with tracking it scores an average detection accuracy of 80-90%. Further the average accuracy of the position detection is 3 centimeters. One problem occurring repeatedly is that the algorithm fails to differentiate between the next plants if they grow into each other and the cluster connect.

What is my analysis of the identified problem, idea and evaluation?

The idea to use a low cost 3D sensor is quite good because, as mentioned in the paper, it works independent from existing lighting and is robust against fog and dust - conditions which occur frequently in the real world. The algorithm uses only a bounding box of a cluster to determine the position of the plant. This approach works okay when every plant grows neatly far away from their neighbours but fails in messy real world conditions. Some aspects are great on the other hand, it has a fast runtime, for example. I think this given approach would work better on a row basis and maybe use offline compute power to identify the individual plants? Because measuring these plants is a repeated operation, one could leverage the result of a computational more expensive offline algorithm and map the online point cloud directly onto an existing map.

What are the contributions?

This main contribution is an evaluation of a low-cost 3D lidar scanner with an basic point clustering algorithm in real time. besides that they also showcase other approaches for the same problem using traditional 2D camera systems and different scanners.

What are the future directions of the research?

The future research will include using stronger machine learning algorithms for clustering and plant separation. They also want to work on a row detection basis.

What questions have I left?

My main concern was the quite simple simulation model on gazebo and i hope that they improve this.

What is my main take away from this paper?

It is possible to detect plants in real time using point clouds in the agricultural sector even with simple mathematical methods. The difference between a classical and those FX6 laser scanner is also interesting. I think plant detection like this is the way to go, by improving only the algorithm it should be possible soon to deploy at least field scouting robots in real world scenarios.

Summary

In depth paper for clustering point clouds into individual plants using a bounding box approach. Maths is explained nicely, can be used to build something similar.

Rating

4/5

9 Reading Report: *Agricultural robots for field operations: Concepts and components*

(Bechar & Vigneault, 2016)

Abstract

This review investigates the research effort, developments and innovation in agricultural robots for field operations, and the associated concepts, principles, limitations and gaps. Robots are highly complex, consisting of different subsystems that need to be integrated and correctly synchronized to perform tasks perfectly as a whole and successfully transfer the required information. Extensive research has been conducted on the application of robots and automation to a variety of field operations, and technical feasibility has been widely demonstrated. Agricultural robots for field operations must be able to operate in unstructured agricultural environments with the same quality of work achieved by cur- rent methods and means. To assimilate robotic systems, technologies must be developed to overcome continuously changing conditions and variability in produce and environ- ments. Intelligent systems are needed for successful task performance in such environ- ments. The robotic system must be cost-effective, while being inherently safe and reliabled human safety, and preservation of the environment, the crop and the machinery are mandatory. Despite much progress in recent years, in most cases the technology is not yet commercially available. Information-acquisition systems, including sensors, fusion algorithms and data analysis, need to be adjusted to the dynamic conditions of un- structured agricultural environments. Intensive research is needed on integrating human operators into the system control loop for increased system

performance and reliability. System sizes should be reduced while improving the integration of all parts and com- ponents. For robots to perform in agricultural environments and execute agricultural tasks, research must focus on: fusing complementary sensors for adequate localisation and sensing abilities, developing simple manipulators for each agricultural task, devel- oping path planning, navigation and guidance algorithms suited to environments besides open fields and known a-priori, and integrating human operators in this complex and highly dynamic situation.

Keywords

Agricultural robots, Robotics, Field operations, Autonomous

Questions

What are the motivations for this work?

The main subject of this paper is to show the current development, ideas and problems in the field of agricultural robotics. This review paper explains first the background, then the economic feasibility and furthers goes into concepts, principles and components.

What is the proposed solution?

The paper concludes, that with current technologies the broad usage in commercial farming is not possible yet and proposes to focus research on a number of fields. Those fields include sensor fusion for better localisation, engineering of better simple manipulators and the development of specific path planning, navigation and guidance algorithms for agriculture.

What is the work‘s evaluation of the solution?

This question is not applicable.

What is my analysis of the identified problem, idea and evaluation?

The authors make a great job in displaying the current technologies and their limitations. With this knowledge it is easy to identify a subproblem to work on.

What are the contributions?

Several points come to the mind. Firstly they create an in-depth background needed to understand the need of automated systems in agriculture, but also explain why it is so hard to create such systems. They propose a categorization of robotic system after the structure of their environment and object of interest. Both can be either structured or unstructured. This categorization creates four different categories. First, a structured environment and a structured object: This is the industrial domain. Second, a strucutred environment and a unstructured object: the medial domain. Further there is the unstructured enviroment with a structured object: the military, space, underwater and mining domains. The last domain, unstructured in environment and object of interest is the agricultural domain.

The next contribution are guidelines under which circumstances a robot can be commercially successful. These guideline conclude that it is possible to start using robots even if the costs are the same as conventional methods if the work of the robots create more steady and predictable processes.

A big part of the review are categorization concepts, components and principles. These include Human-Robot-Systems versus Autonomous Robot Systems. In the component section the authors underline following topics: steering and mobility, sensing and self-localization, path planning and guidance and last but not least, manipulators and effectors.

What are the future directions of the research?

This question is not applicable.

What questions have I left?

Many questions, this paper is an excellent basis for further research.

What is my main take away from this paper?

One of the main problems is the highly dynamic environment and the need to react fast to unprecedented situations. This creates the question on how to define behavior in such a way to allow and strengthen the capabilities of improvisation.

Summary

In-depth review paper with some self citations but besides that it gives many new points to deepen my reseach.

Rating

5/5

10 Reading Report: *Agricultural robots—system analysis and economic feasibility*

(Pedersen, Fountas, Have, & Blackmore, 2006)

Abstract

This paper focuses on the economic feasibility of applying autonomous robotic vehicles compared to conventional systems in three different applications: robotic weeding in high value crops (particularly sugar beet), crop scouting in cereals and grass cutting on golf courses. The comparison was based on a systems analysis and an individual economic feasibility study for each of the three applications. The results showed that in all three scenarios, the robotic applications are more economically feasible than the conventional systems. The high cost of real time kinematics Global Positioning System (RTK-GPS) and the small capacity of the vehicles are the main parameters that increase the cost of the robotic systems.

Keywords

Agricultural robots, Grass cutter, Autonomous vehicles, Economics, Feasibility study, Robotic weeding, Crop scouting

Questions

What are the motivations for this work?

The papers main focus lies on displaying the cost reduction possible by utilizing autonomous system for agriculture tasks. Most agricultural task can not use individual-plant-based solutions with conventional methods. By using robots and big data processing it will be possible to care for each plant individually. Taking care of an identified weed patch for example will need much less herbicides than spaying the whole field preemptively.

What is the proposed solution?

The authors propose solutions for using autonomous robots for field scouting - the identification and localisation of growing weeds -, intra-row and near-crop weeding and automated grass cutting.

What is the work‘s evaluation of the solution?

In all scenarios the authors showcase a reduction in primary and secondary costs in comparison to conventional methods.

Field scouting 20% cost reduction in labor and secondary benefits of the data because it is now possible to only deploy herbicides where needed.

Weeding Only by reducing the cost of the navigation system by half it is possible to save 12-21% or manuel costs. and reduction of herbicide use of 90%

Grass cutting Reduction of cost of 52% (but only when paying the gardener 27 Euro per hour, lol)

What is my analysis of the identified problem, idea and evaluation?

The usage of automated systems for growing crops is one of the key points in reducing the environmental footprint of large scale agriculture. The three analyzed areas are great entry points for deploying such systems. Especially the field scouting and the automated weeding are very interesting. For the evaluation the authors compared the costs of the components with average conventional costs witch is mostly reasonable, expect the estimated labor cost of the gardener of 27 Euros per hour for grass cutting.

What are the contributions?

The ideas of the authors in breaking down the cost of the robots into several components are very helpful to estimate economic costs of different system for this usage. The main contribution is this economic analysis which helped to spark more research in this direction.

What are the future directions of the research?

There will always be economic analyses for newer technology.

What questions have I left?

Because this paper is from 2006 I am eager to find a similar, more current breakdown.

What is my main take away from this paper?

That it is feasible to automate many agricultural tasks with almost existing technology.

Summary

Great in depth analysis but dated (2006), has good numbers for conventional cost estimates.

Rating

3/5

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