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Humanoid test target for the validation of sensor systems on autonomous agricultural machines

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In the field of safe environment perception of autonomous machines, a realistic humanoid test target is an enabler for the validation of object detection systems for the protection of persons as a key technology. The working area of autonomous mobile machines, such as agricultural machines, is mostly in public outdoor areas. These areas are particularly demanding for object detection systems. In addition to difficult environmental conditions, an exclusion of certain categories of people, such as children, in public areas is not possible as compared to non-public areas. There are standard test targets available either for public outdoor areas or for autonomous systems, but not for the combination of both. For this reason, the following article establishes criteria for such a test target and realized a test target based on experiences from both domains. The new test target has been applied for the evaluation of perception systems in agriculture in cooperation with TÜV. It is a proposal for a humanoid test target for the validation of sensor systems on autonomous agricultural machines.

Autonomous agricultural machines are taking over more and more tasks. The milking process for example, as the main process in milk production, is already fully automated. Automatic feeding systems have also established themselves on the market. However, these systems only take over part of the feeding process chain. Work of the authors on a fully autonomous system, which integrates the full feeding process is presented in Figure 1 and in MELTEBRINK et al. (2018).

For autonomous systems, the issue of product liability is a current topic. However, one important point cannot be neglected in the automation of mobile machines. As the level of automation increases, the safety measures for personal protection must increase in the field of environmental protection of autonomous machines. GALVAO et al. (2021) give a review of pedestrian and vehicle detection in autonomous vehicle perception systems. In all cases of autonomous machines or vehicles, safe, non-contact sensor systems as perception systems are a key technology in this regard. Object detection systems (ODS) are solutions to detect objects especially as well persons.

Figure 1: The autonomous feeding mixer "Verti-Q" in a typical working environment (© B. Strautmann & Söhne GmbH u. Co. KG)

ODS are sensor systems that combine a measurement unit (sensor) and the measurement data interpretation. For the measurement unit, different measurement principles (e. g., LiDAR, radar, …) can be used. The results of the measurement units are measurement principle-dependent raw data. The different measurement principles each have different strengths and weaknesses in relation to the environmental conditions at the point of use. The measurement data interpretation tries to interpret the raw data and decides if an object is detected or not. For ODS, persons are also objects and are recognized as such. For this reason, ODS are tested as perception systems to detect persons on autonomous mobile machines. ODS are also defined in the standard ISO 16001:2017-11. Li et al. (2020) provide for example the use and an overview of the state of LiDAR technologies in the automotive sector. As described in the IEC 62998-1:2019 standard, sensor systems, such as ODSs, must be sufficiently validated in the intended area of use for personal protection. Meltebrink et al. (2021) present a test method and its first realization with a test stand, which validate the functionality of an ODS for the safe detection of persons on autonomous agricultural machines directly in the farm environmental conditions. Thus, the detection capability of the ODS is tested directly in possible outdoor environmental conditions, such as fog and rain. The measurement principles of the tested ODS range from camera systems, LiDAR and ultrasonic to radar technologies.

The testing and validation of non-contact protection systems are essential in the development of autonomous agricultural machinery and an important component of agricultural worker safety. For this purpose, with a humanoid test target, continuous outdoor tests are necessary in the planned area of operation with its different environmental conditions based on the standard IEC 62998-1:2019 for safety-related sensors used for the protection of persons. The new proposal for a humanoid test target was used by Meltebrink et al. (2021) as a new test target on a dynamic test stand in a long-term test for 365 days a year and 24 hours a day in continuous outdoor use and different environments (Figure 2).

Figure 2: The project "Agro-Safety" used the new test target on a dynamic test stand in a long-term test for 365 days a year and 24 hours a day in continuous outdoor use and different environments (© C. Meltebrink)

Objectives of work

A test target for mobile autonomous machines in public outdoor areas is sought. For example, autonomous agricultural machines are built to take over certain tasks completely. If a machine is fully autonomous, it is assumed to be an unmanned machine. In the area of functional safety, the responsibility to prevent personal injury is an essential point. The requirements for safe person detection should be greater than for machines where the human fallback is still present in the event of an emergency. In the case of manned machines, the term "assist systems" is often used. These kinds of systems are built to assist the operator to prevent personal injuries. The operator is still a human fallback level and is still responsible. In the subsequent comparison of different existing test targets, the properties of a test target differ greatly whether it has been defined for manned or unmanned machines or vehicles. For this reason, it is important to pay attention to whether a test target is designed for manned or unmanned machines or vehicles.

The other important factor is the environment (e.g. indoor or outdoor) of the working area of the mobile machine. Area is an important factor for a safe person detection with ODS. Regarding the different strengths and weaknesses of the different measurement principles, the working area is an important factor for a safe person detection with ODS. The working area has another important influence. It must be considered whether it is a non-public or public area. In non-public areas, the access of certain categories of people, such as children, is restricted. A large variety of categories is present in public areas, and an exclusion of certain categories is not possible. Recognizing and assessing the behavior of these certain categories fundamentally influences the safe detection of persons by ODS in case of autonomous machines. If these two factors are considered in the search for a suitable test target, Figure 3 shows the problem that there is no suitable test target for unmanned machines in the public area.

test targets		mobile machine	
		manned	unmanned
working area	non-public areas	available	available
	public areas	available	not available

Figure 3: Overview of test targets for different types of mobile machines in their different working areas

There are no standards with a defined test target for personal protection on unmanned mobile machinery in public outdoor areas. Standard test targets exist either for public outdoor areas or for autonomous systems, but not for the combination of both. For this reason, the main objective of this article is to present preparatory work in cooperation with TÜV as a proposal for a standard test target for the validation of personal protection on autonomous mobile machines in public outdoor areas based on experiences from both domains.

Using this new test target, its' reflection properties will change due to outdoor environmental influence. The detection capability could be better or worse. Consequently, there is a risk of non-detection. For this reason, the properties after 12 months of use are measured and compared with the original test target in this work.

The working area of agricultural machines is in semi-public areas, such as cultivated fields. The distinction between a semi-public and public area is not necessary for this article, as access is not restricted in both areas. No certain categories of people can be excluded and for the development of a test target, a distinction is not necessary.

Overview of humanoid test targets

The following sections present test targets and their properties that are already used in different fields of application. The test targets are assigned to their domains. Thus, an overview is given, which test targets for ODS already exist in the industrial sector, in the mobile machinery and for the automotive sector. Here, the focus is restricted to standard test targets that are based on public standards and are suitable for non-contact sensors or simulate a human body as realistically as possible. The use of already standardized test targets or their properties from other application areas is an essential basis for a new proposal for a standard humanoid test target.

Industrial sector

The IEC 61496-3:2018-12 standard defines safety requirements for electro-sensitive protective equipment. In part 3, the standard defines particular requirements for active opto-electronic protective devices responsive to diffuse reflection (AOPDDR).

The ISO 3691-4:2020-02 standard defines safety-related requirements and their verification for driverless industrial trucks and their systems. It does not exclude the use in outdoor areas with electro-sensitive protective equipment, but operation in public areas is not permitted. In both standards, properties for other measurement principles besides the optical variants are not covered. Examples as draws of test targets in the industrial sector are shown in Figure 4.
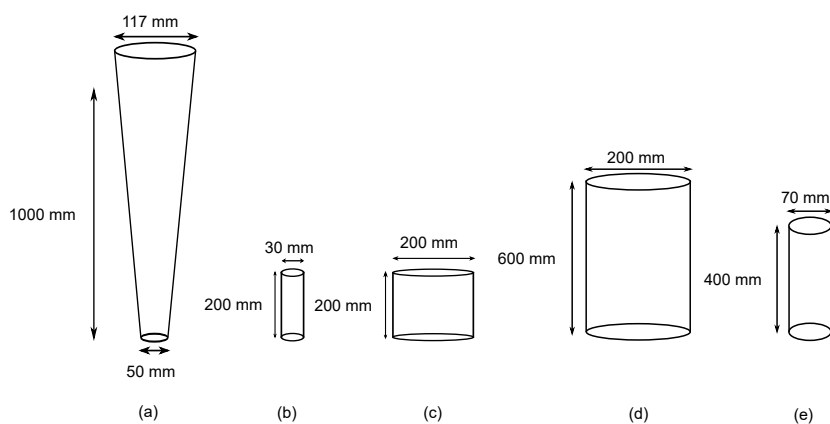

Figure 4: Overview of drafts of the dimensions of the test targets defined in the industrial sector: part (a) test target for the cone-shaped simulation of human legs, part (b) smallest test target, part (c) biggest test target (human body) of the standard IEC 61496-3:2018-12 for 2D protective systems, part (d) big test target, part (e) small test target of the standard ISO 3691-4:2020-02

Mobile machinery sector

For earth-moving machinery the standard ISO 16001:2017-11 defines performance requirements and tests for object detection systems and visibility aids. This standard specifies different test targets for different measuring principles. Examples as draws of test targets are shown in Figure 5.
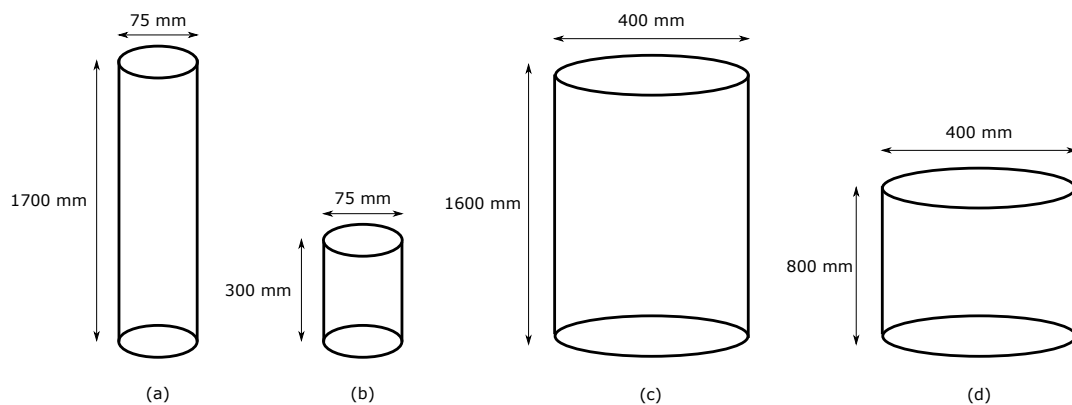

Figure 5: Draft of the dimensions of the test targets defined in the standard ISO 16001:2017-11: part (a) test target for ultrasonic sensor systems, part (b) other test target for ultrasonic sensor systems, part (c) test target for visual ODS, part (d) test target for visual systems with morphological recognition

For mobile machinery in the agricultural sector, a test target for testing the sensors on highly automated machines exits through the ISO 18497:2018-11 standard, representing the torso and body of a seated person (Figure 6), with dimensions based on ISO 3411:2007-07.
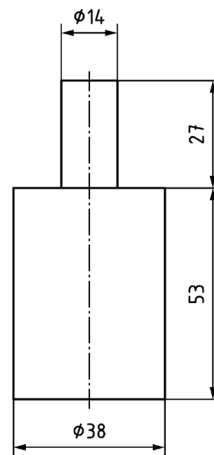

Figure 6: Original draft of the test target "seated person" from the standard ISO 18497:2018-11 (reproduced with permission of DIN Deutsches Institut für Normung e.V.; the version of the DIN standard with the latest issue date is authoritative for the application of the DIN standard)

Automotive sector

The first presented humanoid test target (Figure 7) from the automotive sector is mainly used for accident reconstruction and crash tests (CTS DUMMY-SOLUTION 2020). For this reason, its biofidelity is comparable to that of a human being. Since the main purpose of accident reconstruction is to recreate human injuries, the material of the test target is selected according to the anthropomorphic model to the 50th percentile of a male adult.
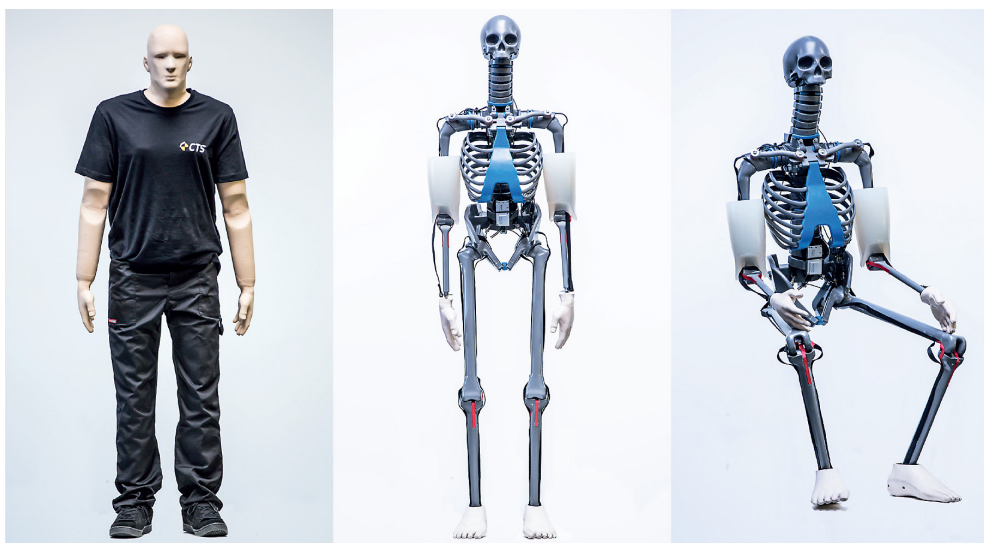

Figure 7: Biophile crash test dummy PRIMUS BREAKABLE (© CTS dummy-solution GmbH & Co. KG)
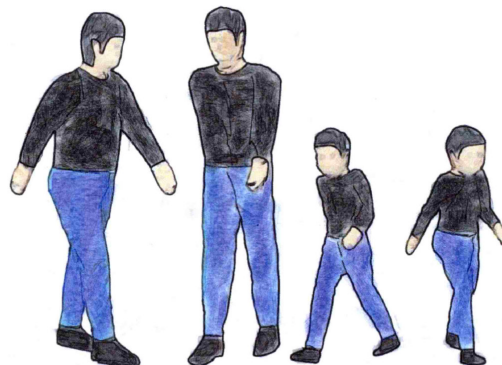
Figure 8: Original draft from the standard ISO 19206-2:2018-12: Visual properties of adult and child target (reproduced with permission of DIN Deutsches Institut für Normung e.V.; the version of the DIN standard with the latest issue date is authoritative for the application of the DIN standard)

The second humanoid test target is used for the testing of driver assistance systems. For example, it is used and developed for the Euro NCAP test for the pedestrian emergency braking assistants. The development is based on different working group results and different humanoid test targets (Lemmen et al. 2013). The result is a pedestrian target (s. Figure 8) defined in the international standard ISO 19206-2:2018-12. There are variants of an adult (a 50th percentile male) and a variant of a child (6 to 7-year-old).

Humanoid test target for autonomous agricultural machines

A test target is needed, which can be used for the validation of unmanned machines in public outdoor areas. Since a perfect imitation of a human is not a realistic option, a – non-perfect – humanoid test target will enable testing with a high degree of automation and/or in situations where the use of a real person is not possible.

Classification of existing test targets

To define a new proposal for a standard humanoid test target for functional safety of autonomous mobile machines in public outdoor areas, it is important to consider the experience and characteristics of test targets of other sectors or use cases. If Figure 3 from the section "objectives of work" is considered, solutions are available for other areas. All these test targets have specific characteristics for the requirements of their application areas and are based on their experience and applications. If the properties and requirements of the unmanned machines in the non-public sector are combined with the manned machines in the public sector, a new proposal for a standard test target for unmanned machines in public areas is created. Nevertheless, it is important to define clear criteria for a test target for unmanned machines in public areas. For this reason, criteria are defined below and then the existing test targets are evaluated accordingly.

Most of the working areas of the mobile machines are semi-public and public areas. These two areas have one thing in common: every person has access to the working area of the autonomous machine. For that reason, the question arises, which age of children must be expected in the working area of a mobile machine. For this purpose, the provision of parental supervision is used. It must be clarified up to what age parents must fulfill their supervisory obligation and from what age children

can be expected on agricultural land. For this reason, a proposal on the parental duty of supervision from the Children's Commissioner of the City of Munich (PFEUFER et al. 2010) is used. There it is defined that "children up to the age of about four should never be left unsupervised by their parents. [...] Until the age of six, parents should check on their child every 10 to 15 minutes." (PFEUFER et al. 2010). Also recommended is that "from elementary school age (in Germany at about age 6), parents can practice "being alone" with their child." (PFEUFER et al. 2010). Based on these two recommendations, it can be assumed that from the age of 6, parents can leave their children alone and they could be in the working area of an autonomous mobile machine. Therefore, children from 6 years of age at least must be expected in agricultural working areas.

Additionally, the working area of a mobile machine influences the selection of suitable object detection systems. ODSs use different measurement principles (single or fusion) to detect persons. On the one hand, there are different reflectivity of people resulting, e.g., from clothes or body shapes. This fact influences the detection capability of each measurement principle. To prevent many non-detections, worst-case properties should be used for the validation of a personal protective system. On the other hand, it is known that the different measurement principles have different difficulties in certain environmental conditions. For this reason, to validate the safe functionality of personal protection on autonomous mobile machinery in public outdoor areas, a humanoid test target has represented a worst-case scenario with respect to a perception system for functional safety. Nevertheless, the choice of a test target must consider the more difficult conditions in outdoor areas as opposed to indoor areas.

The different measurement principles have different strengths and weaknesses under outdoor environmental conditions. Therefore, different measuring principles are combined to achieve a better detection capability and availability. For this reason, it is important for a test target to simulate the worst-case reflectivity of all available measurement principles. These range from optical systems (camera systems, LiDAR, ...) to ultrasonic and radar technologies. Based on this information, the following criteria are defined to compare and rate the presented test targets. For better comparability, all test targets are listed and rated with these criteria in Table 1.

1. Designed for **public areas**: In public areas, all categories of people could exist. That means, exclusion of a certain category, such as children, is not possible;
2. Designed for **unmanned machines**: For unmanned mobile machines, the test target has to simulate worst-case scenarios to prevent many non-detections;
3. Designed for **outdoor use**: The requirements of detection capability of the perception systems, represented by worst-case properties of the test target, have to be adapted to the various disturbances in outdoor areas;
4. Designed for all common **measurement principles** of perception systems: the different measurement principles have different strengths and weaknesses under different environmental conditions. Fusions are used to cover as many environmental conditions as possible. Thus, one test target must also be suitable for different measurement principles.

Table 1: A Collection and comparison of test targets for public outdoor areas

Test target	(1) public areas	(2) unmanned machines	(3) outdoor use	(4) measurement principles
IEC 61496-3:2018-12 (industrial sector)	No	Yes	No	No
ISO 3691-4:2020-02 (industrial sector)	No	Yes	Yes	No
ISO 16001:2017-11 (mobile machinery sector)	Yes	No	Yes	No
ISO 18497:2018-11 (mobile machinery sector)	Yes	No	Yes	No
Biofidel-Dummy (automotive sector)	Yes	Yes	No	No
ISO 19206-2:2018-12 (automotive sector)	Yes	No	Yes	Yes

All test targets presented in Table 1 have certain limitations. The test targets from industry, which are presented in section "Industrial sector", are for unmanned machines in non-public areas. They have the toughest requirements for optical detection capability but are only suitable for optical measurement principles. Additionally, for optical measurement principles like cameras with artificial intelligence, these kinds of test targets are not suitable. These systems need a test target with a shape like a whole human. In this sector, the importance of criteria 3 becomes clear. While IEC 61496-3 defines very strong reflectivity properties for test targets of optical systems in the indoor area, in ISO 3691-4 the environmental conditions of the outdoor area are considered, and the reflectivity properties are adapted accordingly.

The standard ISO 16001:2017 for earth-moving machinery uses different test targets or real persons for different measurement principles and can be used for public outdoor areas, however, children are not considered. Additionally, the focus is on the validation of driver warning systems and that means unmanned machines are explicitly excluded. When using real people instead of test targets, it is argued that "the coherence of the results with real people in different statures is greater than with artificial surrogates" (ISO 16001:2017). Real people cannot be used in the validation of unmanned machines. For the perception system test under environmental conditions, artificial surrogates must be used for long-term tests or initial validations. All other presented test objects only represent individual parts of the human body or represent a human body as a manikin for visual systems. But the manikin is not useful for other measurement principles.

The presented test target for the agricultural sector from the standard ISO 18497:2018 reproduces the upper body and the head of a human by means of cylinders. This does not correspond to the real shapes and proportions of a complete human body. Also, children are not considered. The test target can be used in outdoor areas. The radar reflectivity properties of the human body are emitted by water. In combination with specifications for the surface for visual systems, the test target should therefore be able to be used for various sensor measurement principles. Likewise, no exact specifications are defined for reflectivity properties. The specified use is only limited to highly automated and thus not unmanned machines. In the agricultural sector, it must still be assumed that an unmanned agricultural machine has to recognize not only seated persons. Therefore, the question is how likely is it to encounter a sitting farmer or a standing/walking person in an agricultural area. In addition, the simulation of a person by two cylinders alone is not sufficient for all sensor systems and does not represent a complete person. This was impressively demonstrated in the publication from STEEN et al. (2016).

The first test target from the automotive sector represents a complete human body and it is most like a human body (CTS DUMMY-SOLUTION 2020). Children are not considered. Here, however, the fo-

cus is on the human biological composition for example crash tests. This is a big difference. This test target is primarily concerned with simulating the changes in the human body that would result from an accident in a car. For autonomous mobile machines, a test target is needed, which possesses the reflection characteristics of the usual measuring principles of non-contact sensor systems. ODS with contact sensors are, in most applications of autonomous mobile machines, not suitable regarding the dimensions and speed of machines or the environment. Thus, a simulation of the biological composition pursues a different goal and does not necessarily have the required properties for the validation and testing of ODS.

The second test target for the automotive sector from the standard ISO 19206-2:2018-12 is a test target renowned and tested in the automotive sector; it represents a complete human body, is suitable for different sensor measurement principles and its specifications are for outdoor use and the validation and testing of ODS. Children are considered. Likewise, exact specifications are defined for reflectivity properties. Nevertheless, it was developed for testing driving assistance systems in the case of driving assistance systems, it is assumed that the ultimate responsibility lies with the driver and that the vehicles are not completely unmanned. Thus, the reflectivity properties for different sensor measurement principles correspond to the values of average pedestrians and do not exhibit worst-case values.

The selected basis of test target

In addition to difficult environmental conditions, it is not possible to exclude certain categories of people, such as children, in working areas of mobile machines. Consequently, the humanoid test target, which is standardized in the ISO 19206-2:2018-12 standard and simulates a child aged 6–7 years, was selected as the basis of a new proposal for a standard humanoid test target. It is the only test target, which passes only one defined criterion and is one of only two test targets, which simulates an entire human body. The target was developed and extensively tested for the validation of non-contact sensor systems on vehicles. It already is an accepted test target for driver assistance systems and realized the state of the art as described in the standard ISO 19206-2:2018-12. The acceptance of the test target in the automotive industry is an important argument for this test target, which led to the decision to use and alter it.

The test target "4activePS child (v3v3.2)" from the company 4activeSystems GmbH from Traboch in Austria was used, which manufactures this test target according to the standard ISO 19206-2:2018-12. The test target is only used for driver assistance systems. For this reason, the properties of the test target are not "worst-case" parameters of any measurement principles and passed one criterion. The new proposal of a standard humanoid test target should be used to test unmanned agricultural machines and vehicles. For this reason, certain properties of the test target are modified for worst-case properties based on standards for unmanned systems in non-public outdoor areas. The original test target and the new proposal of a standard humanoid test target is shown in Figure 9 (MELTEBRINK et al. 2021).
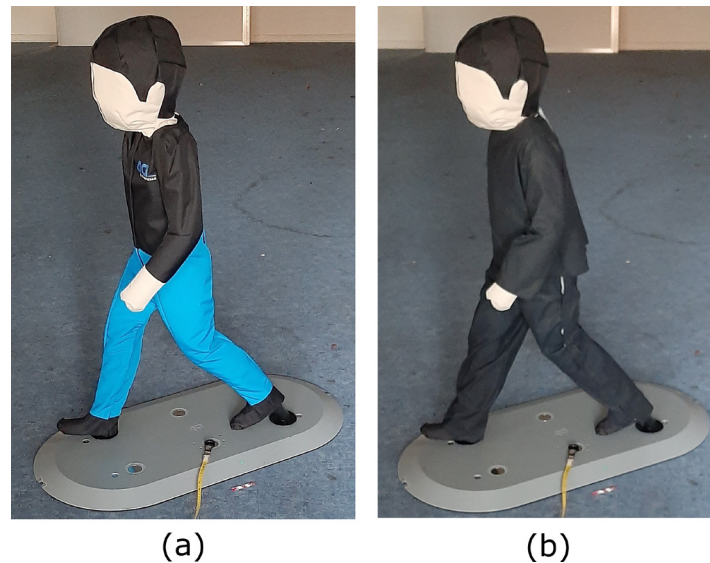
Figure 9: Original test target from 4activeSystems GmbH with (a) the manufacturer material (MM) related to the properties of the standard ISO 19206-2:2018-12 and (b) the new proposal of a standard humanoid test target with the new cotton material (CM) (© Hochschule Osnabrück)

Optical analysis and modification

A reflectivity between 40% and 60% for the near-infrared (NIR) at wavelengths from 850 nm to 910 nm is specified for the clothing and visible skin in the standard ISO 19206-2:2018-12. For hair, a reflectivity of 20% – 60% is defined. Comparing these values to the standard ISO 3691-4:2020-02 for driverless industrial trucks in non-public areas, these values are very high. A test target with a reflectivity of 2% – 6% depending on the location of the vehicle for the validation of unmanned systems is required in the standard. This standard also does not exclude outdoor use and is used in this article.

Due to the high reflectivity properties of the employed test target, a black, outdoor-suitable cotton is used as new clothes. The standard ISO 19206-2:2018-12 specifies a measurement of the reflectivity at a defined angle of 90° and 45° and the measurements must be repeated three times. To compare the measurements with the standard and manufacture measurements, the same measurement setup is used in this project. The reflective properties of the surface of a material can vary selectively. To take the fluctuations into account, measured value ranges are listed within which 100 measurements lie. For general comparison, the average is additionally used. The measurements are in an area of 100 mm length and 100 mm width and a difference of 10 mm between the measurement points. For repeatability, a template of 100 mm length and 100 mm width was created for each of the 90° and 45° measurements. As an example, Figure 10 shows the measurement setup and the template with 90° measurements on the cotton material.
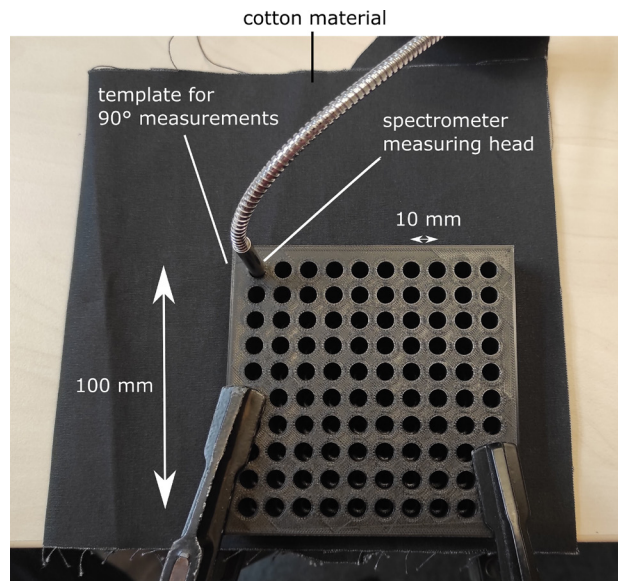
Figure 10: Measurement setup of a 90° reflectivity measurement of cotton material with a spectrometer and a measuring template with 100 measuring points (© M. Strotdresch)

Figure 11 (a) shows the average reflectivity of the cotton material (CM) and the manufacturer material (MM) in the wavelength range from 400 nm to 910 nm. In both diagrams of Figure 11, the data of the cotton material is shown in black and the data of the manufacturer material is shown in green. The range of the visible wavelength from 400 nm to 780 nm is highlighted in blue, and the range of the NIR wavelength from 850 nm to 910 nm is highlighted in grey. On the left diagram (part a) in Figure 11, the data of the 90° measurement is displayed. There are no significant differences between the 90° and the 45° measurements. These differences are shown in part b of Figure 11. In this case, negative differences mean a greater reflectivity of the 45° measurement than the 90° measurement. Positive differences mean a greater reflectivity of the 90° measurement than the 45° measurement.
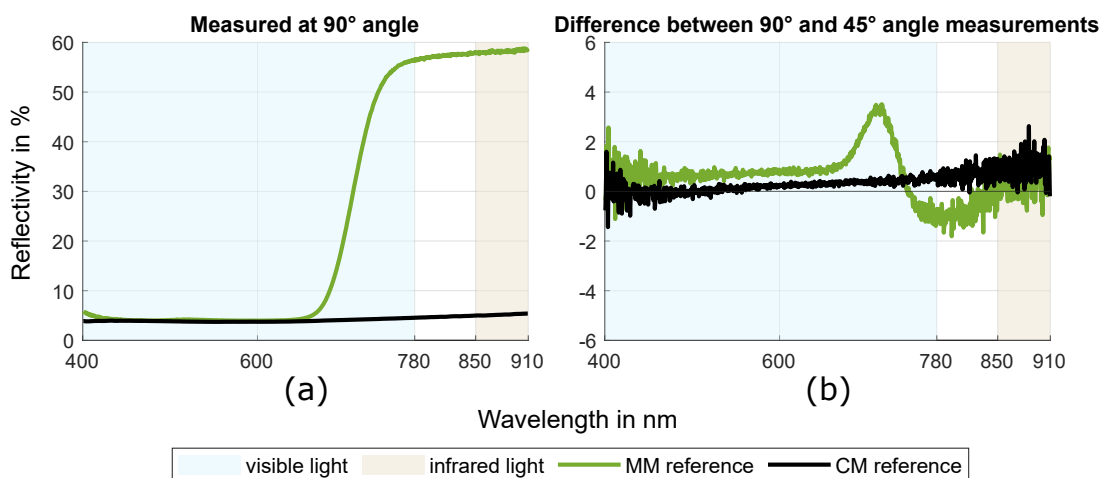

Figure 11: The reflectivity of the cotton material (CM) and the black part of manufacturer material (MM) in the wavelength range from 400 nm to 910 nm; (a) the data of the 90° measurement; (b) the difference between the 45° and the 90° measurement

In the visible wavelength from 400 to 780 nm, the reflectivity of the new cotton material has an average of 3.9% in the 90° measurement with 100 measurement points and falls in the normative range for driverless industrial trucks of 2–6% reflectivity. The material has an average of 5.2% in the wavelength range from 850 to 910 nm and falls as well in the normative range for driverless industrial trucks. In the visible wavelength from 400 to 780 nm, the reflectivity of the manufacturer material has an average of 13.8% and does not fit in the normative range for driverless industrial trucks. The manufacturer material has a reflectivity with an average of 58.2% in the wavelength range from 850 to 910 nm It is shown that the reflectivity is much better than the cotton material and does not fit in the normative range for driverless industrial trucks. The measurement results of the 90° measurement are displayed with the measured average and the range of 100 measurements in Table 2.

Table 2: Results of the 90° measurements with 100 measurement points for the cotton material and manufacture material in the wavelength range from 400 nm to 780 nm and from 850 nm to 910 nm

Wavelength	400–780 nm	850–910 nm
Cotton material (min/max)	3.7–4.5%	5–5.4%
Cotton material (average)	3.9%	5.2%
Manufacture material (min/max)	3.9–56.5%	57.6–58.8%
Manufacture material (average)	13.8%	58.2%

Radar and ultrasonic analysis and modification

The test target was verified with respect to its radar reflection (Thomann and Horstmeyer 2021). For this purpose, tests were carried out with a 24 GHz radar sensor and verified with the manufacturer's data. Comparative measurements with real persons showed that the radar reflection properties of the test target are lower than those of an average male person aged 28. Further comparative measurements with the manufacturer's data confirmed that the test target can be used to simulate the radar reflectivity characteristics of an average person. The selected test target is smaller than the body of the real test person. This relationship could also be measured in the measured lower reflections. Thus, it is assumed that smaller persons, e.g., children, have a comparable radar reflection as the test target. At this point, the question remains whether clothing influences radar reflectivity properties. For this purpose, the effects of clothing on the reflection properties are also investigated using test measurements with the 24 GHz radar sensor and the results are compared with those of Lemmen et al. (2013). It was also confirmed that clothing has a negligible effect on the reflection properties. This refers to a real person as well as to a test target. Thus, the project was able to prove that the new cotton has no influence on the radar reflection properties of the test target. The ultrasonic reflectivity properties of the target are considered realistic due to its cotton clothing and round shape, and thus are not subject to further verification.

Impacts of 12-month continuous outdoor use

The chosen and customized test target manufactured by 4activeSystems GmbH and fitted with an outfit made of black cotton suitable for outdoors was used by Meltebrink et al. (2021). In this context, the test target is exposed to the whole year range of weather conditions in Germany. Due to the

various influences on the test target in the outdoor area, a change in reflectivity cannot be ruled out. To prevent possible non-detections, worst-case properties should be used for the validation of a personal protection system in public outdoor areas. For this reason, it is important to measure possible changes in reflectivity after long outdoor use. A higher reflectivity of the test target increases the risk of not detecting a person in the real device. Therefore, reflectivity measurements were carried out again after one year of continuous outdoor use (Figure 12). The cotton material was measured at these locations: shoulder, upper arm, lower arm, chest, knee, ankle, hip (part of the trousers covered by the upper body garments). The manufacturer material was measured on the shoes and hair, which are the only black colored areas not covered by the cotton material.
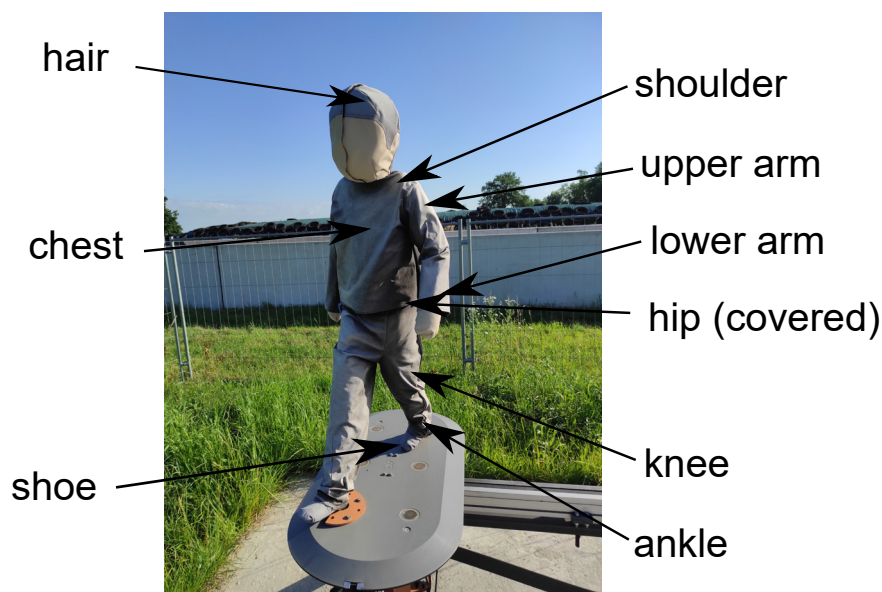

Figure 12: Test target after 12 months in outdoor conditions; the measuring points are marked with arrows
(© M. Strotdresch)

In Figure 13 (a) the average of reference reflectivity measurements at the beginning of the year of the manufacturer material (MM, green color) and the cotton material (CM, black color) are displayed and Figure 13 (b) shows the most important average reflectivity measurements after one year. Part (a) of Figure 13 shows the average reference measurements of the reflectivity of the manufacturer material (MM) in green and the cotton material (CM) in black. Part b of Figure 13 shows selected average reflectivity measurements of the cotton material after one year of outdoor use by means of 4 colored curves representing the different measurement locations. The two dashed lines represent the MM whereas the continuous lines represent the CM. The range of the visible wavelength from 400 to 780 nm is highlighted in light blue, and the range of the NIR wavelength from 850 to 910 nm is highlighted in grey. The main statements of the figure are that every measurement differs from the reference measurement and although the CM has deteriorated, it still has a lower reflectivity than the MM after one year. Nevertheless, the deteriorated CM has an up to 4.4 times higher reflectivity than in the beginning.
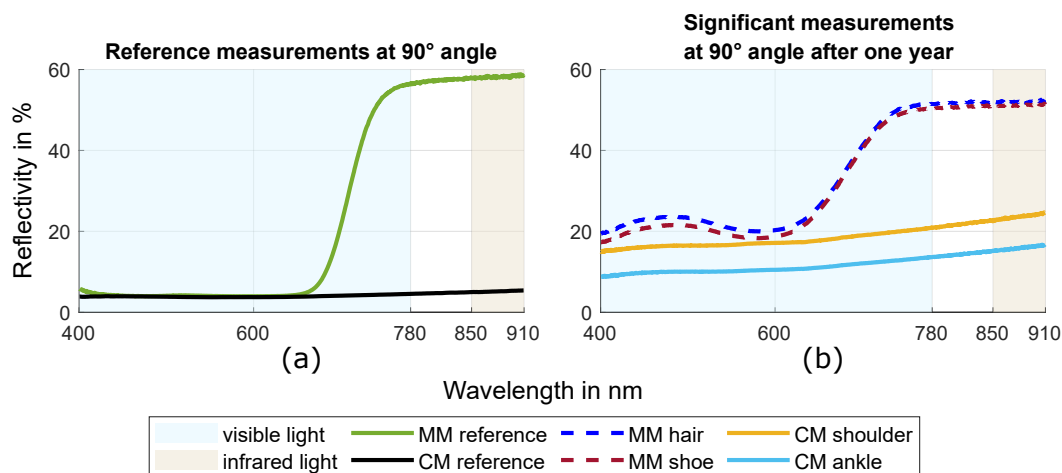
Figure 13: Reflectivity measurements on the test target after one year of continuous outdoor use (b) and compared with (a) the two reference measurements of the manufacturer material (MM) and the cotton material (CM) at the beginning of the year

The other 5 measurements on other, different parts of the test target, showed a similar reflectivity between the range of the yellow shoulder line and the blue ankle line. Only the measurement of the mostly covered hip area was different. Its graph is close to the reference measurement due to the little exposure to the environment over the past year. The measurement results are shown in Table 3.

Table 3: Results of 90° measurements with 100 measurement points for the cotton material and manufacture material in the wavelength range from 400 nm to 780 nm and from 850 nm to 910 nm in 12-month continuous outdoor use

Materials	400 nm – 780 nm	850 nm – 910 nm
Cotton material reference	3.9%	5.2%
Cotton material ankle (after one year)	10.9%	15.9%
Cotton material shoulder (after one year)	17.5%	23.6%
Manufacture material reference	13.8%	58.2%
Manufacture material shoe (after one year)	27.6%	51.2%
Manufacture material hair (after one year)	29.1%	52%

Conclusions

This article defines a humanoid test target for the validation of sensor systems on autonomous agricultural machines. This test target arises from the combination of existing test targets and their properties from other application areas. Important is the special view of the working area in combination with manned or unmanned machines. Regarding the working area, it is important to consider whether the test target is to be used in a public or non-public area. The distinction between manned and unmanned machines with respect to autonomous machines is also an important criterion since the expectations of perception systems are clearly different due to the assignment of responsibility. Standard test targets exist either for public outdoor areas or for autonomous systems, but not for the

combination of both. Moreover, different ODS use different measurement principles (single or fusion) to detect persons. On the one hand, different measurement principles have different difficulties in certain environmental conditions. On the other hand, the reflectivity of persons is influenced by different clothes or body shapes. To validate the safe functionality of personal protection on autonomous mobile machinery in public outdoor areas, the difficult condition in outdoor areas must be considered for the choice of a test target. Nevertheless, a humanoid test target is needed that covers worst-case scenarios with respect to a perception system for functional safety. Based on the strengths and weaknesses of different measurement principles in outdoor areas, some ODS combine different principles to achieve a better detection capability and availability. For this reason, it is important for a test target to simulate the worst-case properties of all available measurement principles.

With respect to the described criteria and the current state of the art, existing test targets were evaluated and compared with each other. The test target from the standard ISO 19206-2:2018-12 was selected as a basis. This test target missed the worst-case scenarios with respect to a perception system for the functional safety of unmanned machines. It is already used to validate driving assistance systems. For an ODS with an optical measuring principle, the test target is dressed in new clothing made of black cotton. The newly achieved values were in turn confirmed by another standard ISO 3691-4:2020-02 from the industrial environment, which sets standards for driverless industrial trucks and their systems. The test target was verified regarding its radar reflectivity properties (THOMANN and HORSTMEYER 2021). The ultrasonic reflectivity properties of the target are considered realistic due to its cotton clothing and round shape, and thus are not subject to further verification.

Based on the standard IEC 62998-1:2019-05 for safety-related sensors used for the protection of persons, continuous outdoor tests are necessary in the planned area of operation with its different environmental conditions. Regarding this continuous outdoor use of the test target, a study of the influence of environmental conditions on the reflectivity of the test target during one year was conducted. Due to these changes, the cotton material is no longer in the standard range, but it is still well below the manufacturer's material in the NIR range. In such tests, it is important to measure the changes of reflectivity of the test target during usage in the outdoor area, as this may increase the risk of not detecting a person.

Based on the results of this article, the test target could be extended with movements of limbs and a simulation of the body temperature. Here, it is already possible to make use of results from the automotive sector and the specified standards. Likewise, other materials could be investigated whose aging process is less than that of the current cotton material. An approach to be investigated would be the use of neoprene as a skin imitation, combined with a hard plastic child manikin, filled with water and an aquarium heater. Also, to be investigated are manikins made of polyurethane or child manikins made of silicone for their reflective properties, combined with clothing with integrated heating such as heating vests.

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