

Review

The Problem of Removing Seaweed from the Beaches: Review of Methods and Machines

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Abstract: Beach cleaning and algae collection in the shoreline area are important for the tourism industry, mainly for aesthetic reasons, but also to protect human health. In addition, the collected material can be used in many industries such as energy, medicine, cosmetics or catering. The problem of cleaning the shoreline area concerns the need to clear land, water and the strip of shore and land onto which water is thrown from falling waves. The vast majority of available cleaning methods are adapted to cleaning beaches or waters. There is a lack of solutions and machine designs suitable for cleaning the coastal strip, which includes: land, the area of land on which the wave is thrown, shoal and deep water. This area is particularly important for tourism as it is mainly used for water bathing. Pictures from tourist areas that are exposed to intensive water contamination show that measures taken to clear the shoreline area are not very effective, as seaweed in shallow water is thrown ashore with the waves. The paper presents a review of methods for cleaning coastal waters and beaches from contamination. It also shows the author's conceptual design adapted to clear the shoreline area and sandy beaches.

Keywords: cleaning the beaches; seaweed removal; enhancement of tourist qualities; non-road machinery; small engine; adaptive steering



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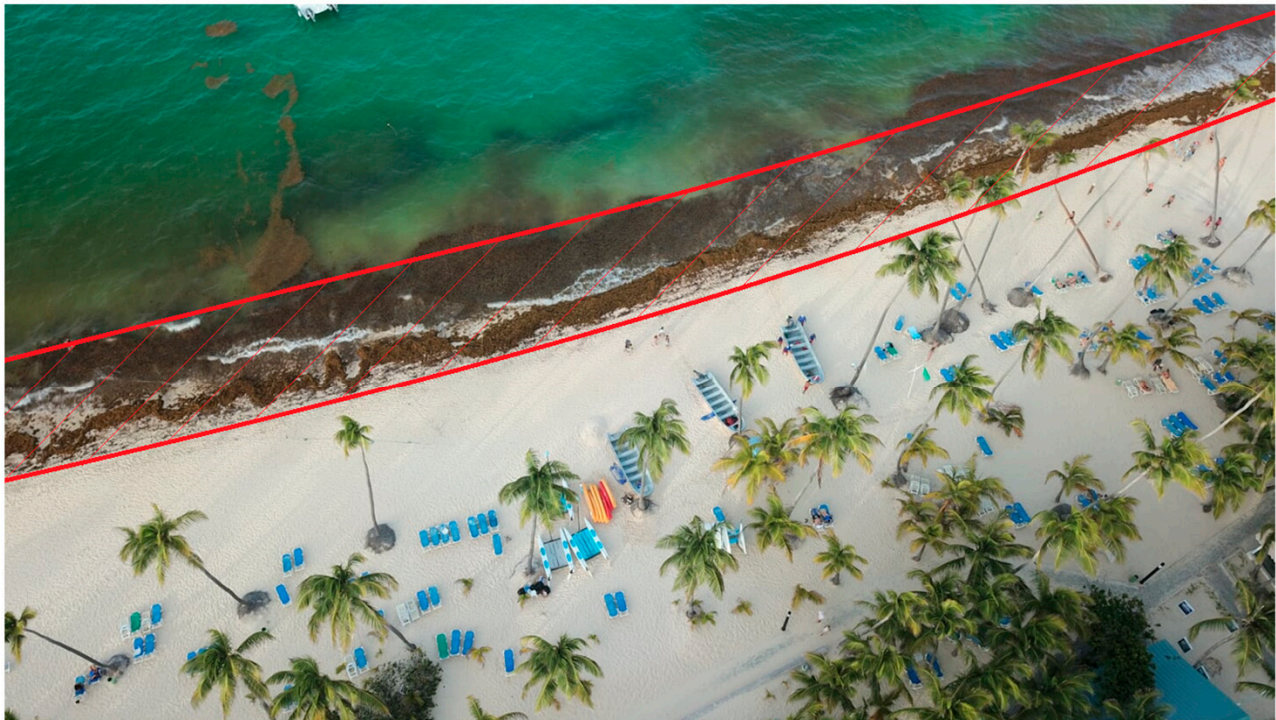
1. Introduction

The 21st century is a period in the history of the world characterized by high levels of pollution. The negative effects of human activity are visible on the beaches of lakes, seas and oceans. Anthropogenic pollution [1–3] and natural seaweed and algae [4] are observed in those places. Human beings contribute directly to anthropogenic pollution, e.g., through ship recycling [5–12] or accidents of structures that operate on water [13–17].

Human activity contributes indirectly to the second group of natural pollutants by providing nutrients to aquatic plants [18]. The main factors of this pollution are land-based agriculture and inefficient or malfunctioning wastewater treatment plants. Improper storage or excessive use of fertilizers contributes to the enrichment of open water reservoirs with biophilic elements, resulting in an increase in trophy, or water fertility [19]. Ineffective or defective wastewater treatment plants similarly contribute to the eutrophication of water bodies [20]. Excessive levels of nutrients in surface waters, and the parallel overfishing of ocean and marine ecosystems [21], result in an excessive amount of algae in waters. The transport of algae in surface waters depends mainly on the water circulation, and the wind causing waves [22–25]. The density of an algal colony changes and mainly depends on the daily cycle of irradiation [26,27], but other environmental factors also influence this parameter, including: nutrients, radiation intensity, temperature and salinity [28–30].

Seaweed pollution in the Caribbean can be seen in Figure 1 [31]. Beach pollution is an important problem for the tourism industry. For some countries this industry is a major source of income [32], allowing for socioeconomic development [33] and national development [34]. Studies by Tudor and Williams on the opinion of visible pollution on beaches

indicate that pollution of human origin, mainly sewage, is the most unfavorable [35,36]. Among the natural pollutants, seaweed is the main problem [35]. In the evaluation of recreation sites, beach and coastal water cleanliness was a very important parameter among the evaluators [36]; hence, great emphasis is placed on their cleanliness. A beach assessment system was developed and implemented as early as 1989–1991 to rank the main public recreational beaches along the open seacoasts in the USA on the basis of 50 criteria. The survey was oriented towards beaches for swimming, and therefore, water quality is also important for them [37].



 - the most polluted area of beaches

Figure 1. Seaweed pollution on the coast of the Dominican Republic in the region of the city of Punta Cana.

Both beach cleaning and algae collection are of interest to several industries. This includes the tourism industry and the authorities of agglomerations that border polluted beaches, mainly for aesthetic reasons, and to protect the health of residents. However, there are also species of algae used in the medical [38], cosmetic [39,40] or catering industries [41,42].

There are papers available describing technologies that use algae as biomass [43] or biofuels [44–46]. M. Hannon suggests that algal biofuels may be a viable alternative to fossil fuels; however, this technology must overcome many obstacles before it can compete in the fuel market and be widely implemented [47].

Kirkman and Kendrick indicated that the ecological and commercial importance of the harvesting of drifting seaweed deposited on beaches is not clearly recognized, using the example of Australia. This is partially because the impact of cleaning the beaches from seaweed on the feeding and nesting of shorebirds is unknown [43].

In addition, a concept with a proposal for a device to clear the coastal and near-shore belt is presented. The area of application of the device is characterized by specific operating conditions resulting from the action of waves that flood the land. As a result, the devices used on water cannot be used to clean water, because of the water level being too low and the possibility of depositing on the shoal. In contrast, land-based cleaning equipment and methods cannot be used because of the risk of flooding or getting stuck. Algae and seaweed left in the cleaned water of the coastal and near-shore belt pollute the beach and make tourists uncomfortable to use of the waters of the coastal and near-shore belt. An additional

difficulty in the development of such a device is the diversity of beach profiles [48], but the developed design of the device is adapted for use on most sandy beaches.

The authors of the article identified the area that most affects the pollution of beaches, according to Figure 1. This area is located in the seaward strip that includes the land and water areas and is one of the most important tourist and recreational attractions. The aim of the article is to demonstrate the methods and machines adapted to purify beaches, coastal waters and the area of the coastline. The methods of floating booms used, for example, on the beaches of Puerto Morelos (Mexico), or the method of tractors with sweepers used on the beaches of Cancun (Mexico) [31], seem to be ineffective. In addition, an innovative concept with a proposal for a device to clear the coastal and near-shore belt is presented in this paper.

2. Beach Cleaning Methods and Equipment

Various types of solutions are known in the state of technology to clear the beach from seaweed or other sediments. They are based on structures that are built on trailers and dragged along the sand. A scraper blade shaves a layer of sand and debris from the sand surface. A continuous conveyor transports the sand and debris over sifter bars within the chassis of the beach cleaner. A foraminous sifter separates debris and permits sand to fall back to the beach [49–53]. This type of construction is also known from the production of the company Kassbohrer Gelandfahrzeug AG (Laupheim, Germany) and the common feature of these machines is cleaning by the sieving of sand from dirt. The machines manufactured by Kassbohrer Gelandfahrzeug AG—in their series of machines for beach and sand cleaning—use a shaft equipped with short colters. They move the sand and transport it to the sifter by means of a transmission belt designed for this purpose. The belt is subjected to vibrations in order to accelerate the sieving process. This functionality is offered by the exemplary machine BeachTech 3000. Another solution in its series of machines for beach sand cleaning is used by the company P.F.G. (Longiano, Italia) and Metaljonica S.R.L. (Roseto degli Abruzzi, Italia). In these manufacturers' machines, the working element (wedge) plunges into the sand, performing a reciprocating movement. The nature of the movement of the working element and the appropriate shaping of the sifter have been used in the transport of impurities from the purified material. Solutions based on this principle have been used in machines, such as the NEMO by P.F.G. and the Evolution 165 by Metaljonica S.R.L. In addition, P.F.G. offers machines that operate in a manner similar to that used in the BeachTech series. The main design difference is of the element that moves the sand, which uses blades in place of colters. Apart from this element, the rest of the design of these machines is similar to that used in other machines of this company. The unit separating the impurities from the sand is a perforated sheet, or a metal grate with suitable openings. The perforated plate improves the cleaning process. To further improve the cleaning process, the characteristic movement of the working element is used. Most of the other machines available use solutions that are similar or identical to those indicated. These machines are built in the form of trailers or stand-alone land units. Another group of designs are beach cleaners mounted in the rear of agricultural tractors [54] or in the front of trucks [55]. There are designs that use agricultural tractors with a loading scoop. In the cleaning process, they use its front part for collecting larger debris, and the rear part of the tractor, to which a cleaning system is fitted, for collecting smaller fractions of debris [56]. An atypical machine is a construction of a low-speed vehicle, which cleans the beaches from pollutants originating from oil spills. The machine moves along the beach and sprays liquid nitrogen onto the contaminated area, thus solidifying the oil and sand mixture, so that the mixture can be separated from the uncontaminated sand lying below and is effectively removed from the beach [57]. The limitations of these methods are related to the vehicles used to transport the working elements of the cleaning machines.

Another form of beach cleaning is the use of manual tools. This involves raking up debris left on the beach and loading it behind transport trailers that are pulled from the beach by farm tractors.

3. Methods and Equipment for Water Treatment

One way to keep beaches clean is to clean the coastal water of pollutants. Water purification methods and devices can be divided into those that are able to cleanse the seabed, and those that are not. Cleaning methods can be divided into two categories: manual and those using a water unit. In the manual method, employees separate seaweed with manual tools and then collect it with nets or vacuum pumps. Machines for the water cleaning of plant debris, in most of the available solutions, use a conveyor belt as the working element. An example of such a machine is the Algea Harvester [58] or the ILH6-300 from Inland Lake Harvesters, Inc. (Burlington, VT, USA). In addition, some designs of water units for water cleaning are equipped with a trimmer that cuts the seaweed to enable the harvesting of rooted plants. Another method is to mount the rotating wings to collect debris [59], vacuum pumps [60,61] or booms with nets to catch algae [62] on the water unit. The limitations of these methods are due to the vehicles used to transport the working elements of the sediment cleaning machines on the water unit.

The only device identified by the authors for cleaning the coastal and near-shore strip from pollution is a structure adapted mainly for cleaning it from oil. The design is based on the use of vacuum pumps and is transported by a land-based unit, e.g., an agricultural tractor [63,64].

4. Innovative Concept for Cleaning the Shoreline Area from Algae in Particular

Available designs identified by the authors are characterized by the lack of possibility to clean the coastal and near-shore strip from pollution due to the used transport units of the working elements of the cleaning machines. The authors propose a solution consistent with the patent application P.429660 [65]. The solution according to the invention allows us to clean both coastal waters and sand beaches in the coastal strip, from algae and seaweed in particular, using a land vehicle and a motorboat for the movement (Figure 2).

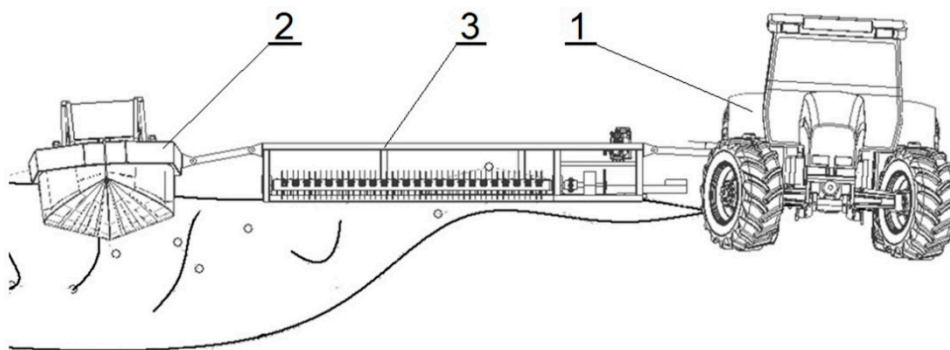


Figure 2. Concept for cleaning the coastal and near-shore strip from algae in particular: 1—land vehicle, 2—motorboat and 3—cleaning device.

A device for cleaning water and sand beaches in the coastal and near-shore strip from algae is shown in Figure 2, where it is depicted in its entirety under operating conditions. The cleaning device is mounted to a land unit and to a water unit with a power engine. This type of mounting will enable the cleaning of the coastal and near-shore strips, where sand and water are cleaned. The entire cleaning module is illustrated in Figure 3, where the module frame, which is adapted for mounting to a water unit and for mounting to a land unit, is shown. The mountings are articulated and provide freedom of movement of the coupled units. The cleaning device is independently driven by a drive unit, which transmits power via a linkage gear to the reducer and then via a clutch to the working shaft assembly. The working shaft assembly is shown in Figure 4 in its entirety. This assembly is attached to the frame via bearing supports. The working shaft assembly is built up from the working shaft shown in Figure 5. The working shaft consists of a hollow shaft with the bearing pins tightly fitted and welded. Spring mountings, to which the torsion springs are fitted on a bolt are screwed onto the work shaft with spring mounting bolts. The collected

algae or seaweed are deposited on the springs and then transferred to a conveyor belt transporting them from outside the treatment area. The flexibility of the torsion springs enables them to overcome terrain obstacles, such as stones, and allows for the cleaning of sandy soils and waters with variable ground contours. The drive unit is mounted in the frame closer to the land unit, but optionally, it can be mounted anywhere on the frame that does not interfere with the working shaft assembly. The operation of the cleaning unit can be managed by the controller of the drive unit, to which the parameter recorders, switches and emergency stop switches are connected to the control panel through electrical cables located in the water unit or land unit.

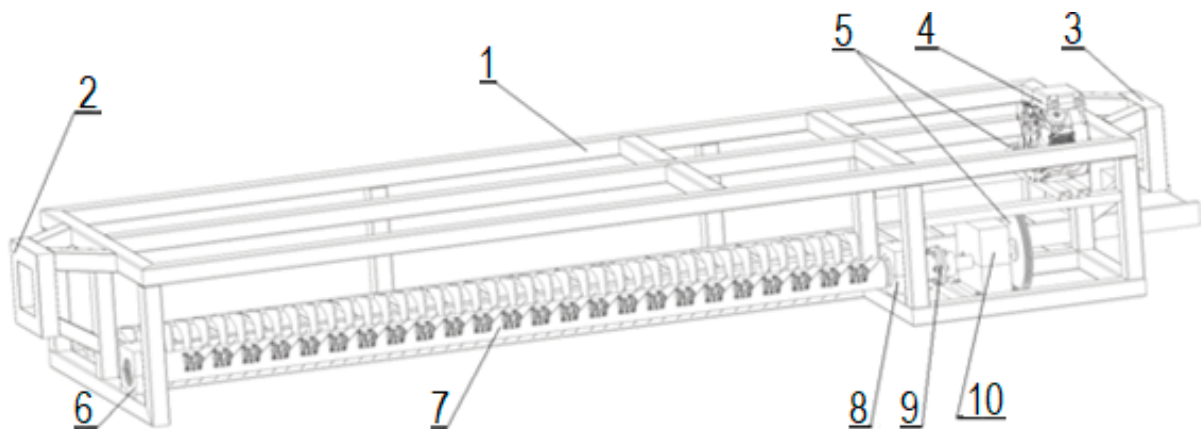


Figure 3. Cleaning device: 1—frame, 2—surface for mounting to a water unit, 3—surface for mounting to a land unit, 4—drive unit of the working element of the cleaning machine, 5—linkage gear, 6 and 8—bearing supports of the working shaft, 7—working shaft, 9—clutch and 10—reducer.

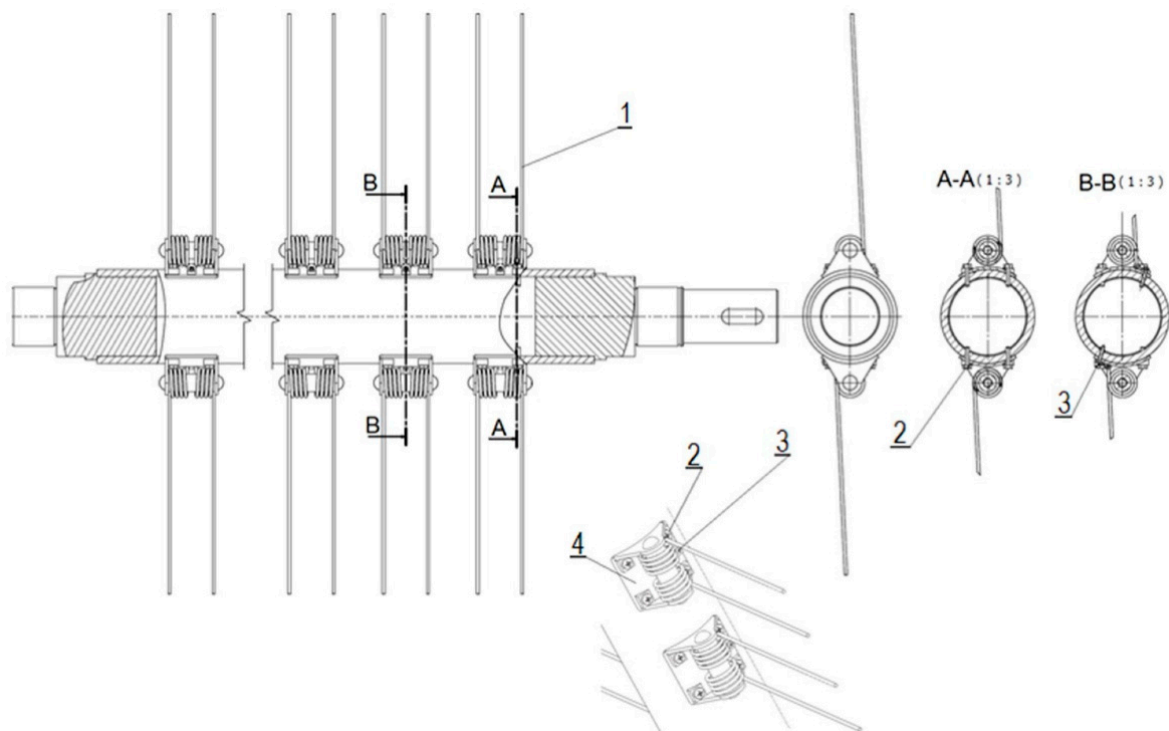


Figure 4. Working shaft of the cleaning machine: 1—torsion springs, 2—spring fixing screws, 3—mounting screws for spring mountings and 4—spring mounting.

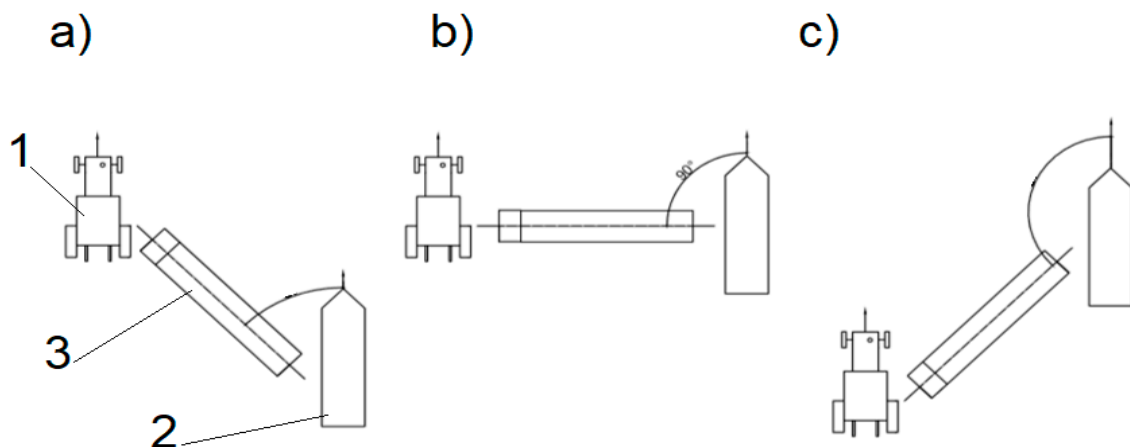


Figure 5. Possible position of the water unit in relation to the land unit: (a) delayed water unit, (b) water unit in optimal position in relation to the land unit and (c) overtaking water unit, where: 1—land unit, 2—water unit and 3—cleaning device.

5. Coupling of the Speed Control of a Land Unit and a Water Unit

An important issue for the developed design is how to control the speed of the land and water unit in such a way as to ensure that the cleaning device moves nearly perpendicular to the direction of movement of the land unit, whose direction of movement is determined by the coastline (Figure 5b). Assuming that the land unit is decisive for the direction and speed of movement due to the greater danger of operation and the possibility of encountering more terrain obstacles, it is necessary for the motorboat's drive to have the possibility of position correction, which can be disturbed by strong winds and sea currents.

The maintenance-free adaptation of the water unit to the land unit with combustion propulsion is ensured by the system and control concept developed by the authors. The mounting to the land unit used for the control process is equipped with a sensor module for the position of the water unit in relation to the land unit (Figure 6). Its purpose is to measure the angular position of the water unit in relation to the land unit through the edge sensors. The module is made up of a sensor for the extreme position overtaking the land unit, a sensor for the extreme position of the delayed movement of the water unit and a sensor for the idle position of the water unit. The sensors are activated by a lever, which is coupled to the position of the cleaning module. Signals from the sensor module of the position of the water unit in relation to the land unit are directed to the air throttle controller of the drive unit of the water unit, adjusting its position in relation to the land unit. The signal of activation of the sensor of the extreme position overtaking the land unit reduces the tilting angle of the throttle of the water unit to the idle position, limiting the speed of the unit movement. The activation signal of the sensor of the extreme position of the delayed water unit movement increases the tilting angle of the throttle of the water unit to a position of higher engine load, increasing the speed of the water unit. The acceleration process ends with a signal from the optimum position sensor. The activation signal of the optimum position sensor allows us to control and support the selection of the optimum speed of the land unit to the water unit. Optionally, a centrifugal clutch in the drive system can disconnect the drive at low speed, e.g., during idle operation. Another optional control function may be to engage the brake or reverse direction of the drive screw by activating the signal from the sensor of the extreme position overtaking the land unit, realizing the analogous process of changing the throttle angle in the motorboat engine.

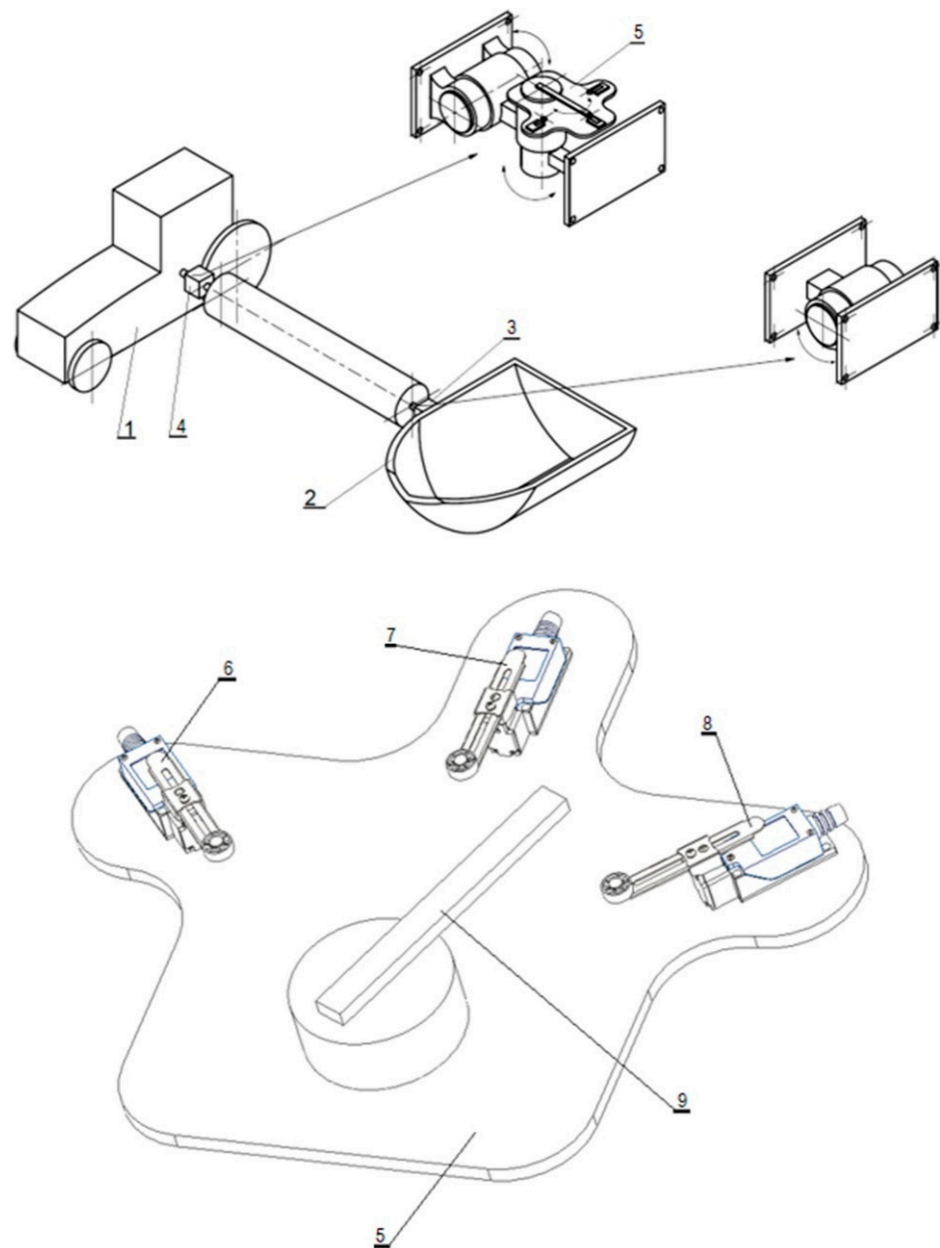


Figure 6. Concept of a system for positioning a water unit in relation to a land unit: 1—land unit, 2—water unit, 3—joint attached to the water unit, 4—joint attached to the land unit, 5—sensor module, 6—extreme position sensor overtaking the land unit, 7—idle position sensor of the water unit, 8—extreme position sensor of the delayed movement of the water unit and 9—sensor activation lever.

6. Discussion

Increased invasion of beaches by seaweed has been observed over the last decade of the 21st century; hence, there are scientific articles describing this issue along with the methods and consequences of dealing with this problem [66]. In the Riviera Maya of Mexico, 4400 people were employed to clean beaches in 2015, but this only targeted 10% of the coast. The scale of the phenomenon indicates the need for the mechanization of the process or the use of hybrid techniques [31,67]. In 2019, tractors with sweepers that combed the beaches were used for cleaning, which somehow improved the quality of the beaches, but these machines did not have the ability to clean water; thus, the cleaning did not fully satisfy the tourists [31]. At the same time, in selected cities in this area, water barriers were applied to limit the flow of seaweed to the beach, without specifying the

method of catching them [68]. In 2016, Hindus et al. indicated that manual beach cleansing resulted in less sand removal from the beach [69]; however, systems are currently being developed to rake collected seaweed. Scientists recognize that the use of sand screening devices is less beneficial to the coastal ecosystem than the innovative solution proposed by the authors, as the screens remove animals, insects or eggs buried in sand [70], while the proposed design only rakes up pollutants from the surface.

7. Conclusions

The available methods of cleaning beaches without the use of machinery seem to be ineffective. On the other hand, machine-based beach cleaning methods are divided into two types of sand-cleaning land-based machines and water-purifying water machines. Most of them are based on sieve screens, the disadvantages of which include shaking animals, insects and eggs out of the sand, and taking up relatively large amounts of sand with the organic material.

There are many methods for cleaning beaches and coastal waters. However, the available technical solutions do not meet the requirement of cleaning the shoreline belt area, which is important from the tourism point of view. The construction concept presented in this paper may fill in this gap in the area of technical solutions for the simultaneous cleaning of the land (beach), the wave-fall area on the shore, coastal shoals and waters allowing the passage of boats.

The conceptual solution was built up from three modules, of which the land unit (e.g., tractor) and the water unit (e.g., motorboat) are commonly available machines, while the cleaning mechanism is a specialized device that can be built from standard components used in agricultural machines. In addition, the cleaning module has its own independent drive, allowing it to work with different land and water units.

The solution can be operated by a single operator as the design allows for matching the position of the water unit to the land unit, realized in such a way that the water unit follows the land unit.

8. Patents

The design solution described in this paper is subject to a patent application in Poland by Szewczyk, J.W. and Warguła, Ł. The device for cleaning the coast and coastal areas, in particular from algae (original text in Polish: Urządzenie do oczyszczania pasa brzegowego i przybrzeżnego w szczególności z alg) was patented at Poznan University of Technology, Poznań, Poland, application number: P.429660, date of filing 17.05.2019.

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