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APPLICATION NOTES

(Terasense® THz-imaging technology)

Item	Description of application case	Remarks
1.	***HOMELAND SECURITY (security screening)*** Identification of hidden objects (e.g. knives, guns, cut and thrust weapons concealed under clothes) when doing a full body security screening at the airports or any other check-points. This application is described at our web-site: http://terasense.com/applications/homeland-security/ http://terasense.com/applications/hidden-oblects-and-defects-identification/ Watch our main promotional videos: ***Terahertz body scanner*** (https://www.youtube.com/watch?v=Y1NZMoimcCo) and ***TeraSense THz imaging camera and THz source (IMPATT)*** https://www.youtube.com/watch?v=oa4ud20x13E) available at (http://www.youtube.com/terasense)	We keep receiving many inquiries, mostly from US-based, European, Malaysian, Chinese and Indian clients. Currently we're negotiating terms & conditions for supply of our huge TERA-18432 (192x96 pixels) THz cameras and THz sources for people screening THz system to China. The customer is choosing between our new concept high sensitive (150kV/W) sensor array and our conventional Thz cameras (50kV/W).
2.	***WIRING Industry - NDT (****non-destructive testing)* Checking wire strands inside the outer isolation (plastic) covering the cable. The wire strand size can be as little 0.1 mm in diameter.	Under consideration by client in Germany
3.	***RECYCLING Industry – NDT, QC (quality control)*** One of our customers in the recycling industry (separating parts of a shredded car) decided to replace or complement their existing X-Ray, Fluorescence and NIR spectroscopy they've been typically using with our THz imaging capabilities (especially useful for dark plastic parts as we found out).	Under advisement by client (who is still evaluating other options for NDT)
4.	***AGRICULTURE - Process Control*** Agricultural sector is keeping pace with other industries, where THz technology has great potential. Our TERA-1024 (4x256) imagers are being used for the purposes of potato selection to handle the problem of separating planting-potatoes from mud clumps and stones – running on conveyor belt. Potatoes can't be washed or rinsed after harvesting and are usually covered in a thin layer of soil. (Before choosing our Terahertz imaging systems the Client had already made some unsuccessful attempts with Hyperspectral and infrared technologies).	Client has purchased linear TERA-1024 (256 x 4 pixels) THz cameras and a few IMPATT diodes and successfully installed them at the factory. They recently requested software upgrade (in the making)
5.	***AUTOMOTIVE Industry - NDT, QC*** We had one inquiry from automotive industry aimed at using terahertz imaging to see if run-flat tyres have some kind of special nylon inserts attached to the alloy wheels (and	Under consideration by client (at the moment holding discussion via our distributor -according to distributor)

	therefore concealed under the rubber tyre precluding visual inspection). Without our THz imaging capabilities at hand, when a vehicle arrives to have tyres fitted, they had to take the tyres off all the wheels, just to check whether nylon inserts on run-flat sections had been installed or not (and check the model of nylon inserts required) and then put the tyres back on.	
6.	***AUTOMOTIVE INDUSTRY - NDT*** We have completed small-scale R&D meant to demonstrate capabilities of our THz imaging systems to indentify the presence (or absence) of steel objects (steel wires etc) inside of rubber tyres and rust on them (in both *Reflection* and *transmission* imaging modes). In all of the cases our THz cameras proved to be perfectly usable (especially in transmission mode), while these test allowed us to establish certain dependence between the thickness of rubber material and our THz capabilities.	We have completed R&D demonstrating successful application and the client is now reviewing other imaging options available.
7.	***FOOD Industry - QC, NDT, process control*** It is a common knowledge that quality control for detection-through surfaces in agricultural and food industries is crucial to avoid using ionizing radiation. So, another simple example is a non-invasive technique used for monitoring the availability/number of hazel nuts inside of chocolate candy (already wrapped and packaged in a box). For instance, one of our distributors in Europe wanted to use (instead of X-ray machine) our THz imaging technology where our THz imaging sensor arrays were meant to handle the task of checking *'if Pick-n-Place Machine has actually put 5x 29g candy Bars into a cardboard carton'*. Seeing through cardboard poses no problem to our THz imagers. However, we needed to make sure that no metal-containing foil is used for any wrapping or packing materials in this case, (because, metal remains to be impervious to THz rays).	Industrial client (via our distributor) is considering our product against alternatives, but we still need to convince the customer to replace its wrapper for metal-free stuff (because the existing wrapper is made of foil, which contains metal particles impervious to THz rays).
8.	***PHARMACEUTICAL & COSMETICS Industries– NDT, QC*** Another specific application associated with quality control in production environment (running at conveyor belt) is running NDT of baby's diapers (nappies) at conveyor belts. We have couple of large industrial manufactures pursuing this direction (however, one of them insists on increasing *imaging speed* (frame rate). Because of that R&D project is underway and the work is humming to improve the frame rate of our sub-Terahertz imagers (it is now tunable via software within the range between 50fps and 0.2 fps) up to the level of 1kHz (1000fps) and even higher ~4 KHz.	Our distributor informed that the Industrial client is 'digesting' the price. This prompted us to sharpen the pencil and reduce the price for ***High Speed Linear Thz imaging camera (TeraFAST-256-HS)*** (http://terasense.com/products/thz-camera/) by more than 50 % since the time of initial negotiation. Another sticking point is spatial resolution. We are pursuing this opportunity and will soon enter another round o negotiations.
9.	***EXPLOSIVES DETECTION – NDT, Security screening*** Another area of interest in the Security field is using THz for explosive detection since common explosives have unique signatures in the 10 to 100 range. This opportunity is also actively pursued by a few customers in India and USA that are deeply involved in defense equipment and nuclear technology.	Terasense experiences challenges in exploring this application (because it is very hard to get explosives for testing (at least legally); let alone the level of hazard associated with testing them. However, we believe the chance is high that our THz imager can detect explosives,

		because some of the modern explosives are known to contain materials similar to plastic, while our THz cameras can perfectly detect plastic object concealed under clothes - watch our video ***Terahertz body scanner*** at (https://www.youtube.com/watch?v=Y1NZMoimcCo)
10.	***OIL & GAS - QC & NDT for Petroleum products*** The clients inquired into our capabilities with respect to identifying the presence of iron and sand particles (small-size fraction) in gas flow supplied under certain pressure. We can say definitely that iron particles are absolutely non-transparent in THz radiation, therefore 100% detectable by contrast in this media. Sand particles in the flow will inevitably cause certain scattering of Terahertz radiation, but will be detectable as well. The quality of the resultant image will largely depend on the speed of flow. This application is rather new for us and requires elaborate contributions.	Completed R&D for one Petroleum Institute that after examining technology. Has purchased TERA-4096 model with lens and THz source.
11.	***FMCG goods - NDT & quality control*** Checking quantity & position of steel bed springs inside a covered mattress.	Terasense is discussing possibilities with one of our European distributors
12.	***FOOD Industry – NDT, QC*** Detecting any plastic debris and plastic parts inside food packaging. This is to avoid any plastic debris inside the food at the end of the production line. This may happen if the plastic debris is too big for the particle aspirator to absorb it. Our cameras can also be used to check the consistency of vegetable oils and cocoa butter.	Terasense is discussing possibilities with one of our European distributors
13.	***WOODWORKING & LUMBERING Industries – NDT, QC*** *Wood analysis* (*Checking wood for water inside*) Wood speed (process) 1m/s (speed of the moving conveyor belt). The application is intended to see if there is water in the wood, (or depending from the "grey scale" how much water there is into the wood) As the water is impervious to THz, so it will appear like dark pinto point The wood type is "softwood" e.g. fir , pine Wood is laminated. Thickness is: from 10mm to 80mm and max width is 400mm.	Very promising application, given proven capability of our THz imagers to see through wood and other materials (see our new video posted at YouTube: ***TeraSense THz imaging camera and THz source (IMPATT)*** at https://www.youtube.com/watch?v=oa4ud20x13E) We requested samples of the wood for profound testing to determine the best wave length and configuration of THz imaging system for this application. Moreover, we complete small scale R&D proving the feasibility of the project (showing that our THz imagers can distinguish wet wood from dry one)
14.	***WIND TURBINE production lines - NDT*** Inspecting composite materials related to Wind Turbine blade fabrication. Detecting concealed defects or extraneous objects inside the turbine blade materials, sometimes as small as 3mm or even 1mm in size.	Terasense has conducted small-scale R&D to determine feasibility and applicability for this application. Client is reviewing results and doing cost-to-benefit analysis for incorporating our system into industrial process.
15.	***BANKS checkpoints - People security screening*** (to detect objects concealed under clothes) Bank is seeking ways to complement other elements of security currently in place (like besides CCTV cameras, metal	This task is feasible and is entirely in sync with Terasense product offering. A full body scan with hidden object samples would look exactly as fragments of a body scan put

	detecting doors (mainly rotating), which respond to concealed threats like firearms by blocking entrance of suspects of carrying them. Bank is investigating other detecting methods based on terahertz imaging, which is 100% harmless and inobtrusive for clients By using natural terahertz body emission, a suitable THz camera could detect dark areas caused by concealed metal objects, since clothing would tend to be transparent. Of course, since they are dealing with bank clients, methods should be as unobtrusive as possible and avoiding people to have to stop or turn around would be desirable.	together into one image (see also Terahertz homeland security and screening). Due to the overall costs such comprehensive *full body scanner system* implies, the price for such an integrated solutions often remains a major deterrent (even for ourselves, as a manufacture). Still we have accomplished what is called the proof of concept (POC).
16.	***LIVESTOCK FARMING (WOOL) – Quality control (QC)*** *Measure the thickness of a wool coat* on a (live) sheep and believe it can be done with THz technology	Considering that flesh (containing blood/water) is impervious to THz rays, we could see the overall profile of a sheep. In THz rays its Wool coat creates certain image over the dark spot of its flesh. Since we can obtain the image of the wool coat, accordingly, we can measure its thickness (indirectly).
17.	***CONSTRUCTION MATERIALS & BUILDING TRADES - NDT, QC*** Using THz imaging camera in building trades to find out moisture in concrete, floor screed, plaster, wall paint and so forth. Successful application depends on many factors: Type and Thickness of material (up to 5-10cm) // internal configuration // Distance to the target // Frequency of the THz generating source, and water content	Building trades should be fairly transparent in THz rays, unless they are wet (because water is impervious). If we are talking about droplets or non-homogeneous inclusions of water inside material, those will show as dark spots on the THz image as compared to the rest of target material. Our engineers do not know where the demarcation line would be between dry material vs. wet material (test are needed).
18.	***AGRONOMY & FARMING – dehydration monitoring in plants*** The water content in vegetative tissues is of high importance to plant scientists, as it is a good indication of general crop health. Water vapor strongly attenuates terahertz waves, and liquid water has an even stronger effect. On the other hand, water also provides a stark contrast in terahertz imaging. Measuring a sample's transmission or reflection properties yields quantitative information on its water content. The high sensitivity of "water-contrast" terahertz imaging also allows in-situ measurements of the water content of plant leaves. This helps avoiding drought stress and optimizing irrigation strategies (e.g., for agricultural crops grown in arid regions). Until recently, one of the only ways to evaluate this parameter was to compare the weight of fresh vs dry leaves. This does not allow for instantaneous or continuous monitoring of the water content in live tissues.	Our THz imaging expert believe that this application is one of the most promising among other NDT & quality control applications of our THz technology. We conducted R&D aimed to take THz images of plant leaves, both freshly cut and in 44 hours and then in 63 hours -to check the difference in dehydration. (Brief report with THz images is available upon request.) Customer is evaluating results and considering leasing our system for field experiments. Our compact and portable THz imaging system can be considered as excellent alternative to ensure effective, accurate and in-situ measurements in field conditions.

	The same applies to checking tree trucks for various plant infections/diseases, as wood is a vary favorable materials for THz imaging!	Our client from Saudi Arabia is considering purchase of a small camera to their agricultural project.
19.	***LETTER AND PARCEL SCREENER*** (freight forwarding, homeland security, security screening) Checking the contents of envelopes and parcels appears to be one of the most promising fields within the whole spectrum of security related applications of our THz technology. Seeing though paper or cardboard or many other commonly used packing materials is a 'peace of cake for us'. Our main promotional video entitled ***TeraSense THz imaging camera and THz source (IMPATT diode)*** available at (http://www.youtube.com/terasense) shows unique capability of our cameras specifically in this field (please watch scene starting at 3:30min in the video).	Our Singapore-based system integrator is now considering purchasing one system for their security screening project. They are now evaluating advantages of THz imaging camera (sized to meet letter dimension) vs. letter-scanner (linear sensor array) which will scan and later integrate single THz images into the whole picture).
20.	***PETROCHEMICAL & CHEMICAL INDUSTRY - NDT & QC*** One of our customers involved in the petrochemical industry is looking for a way to see if products they load in tanktrucks are of good quality and not contaminated with water. The liquids to be checked that are in the focus of attention are diesel, benzin, petroleum, alcohol – all perfectly transparent in THz rays.	Under advisement by one of our customers from Europe working in the petrochemical industry. We are now working with our European-based integrator to create a sensor with sufficient throughput that can monitor the fuel as it is pumped in or out the tank-truck.
21.	***FOOD Industry - QC, NDT, process control*** Reports of insects and other foreign objects found in food are a cause of concern for food manufacturers retailers and consumers alike. Our HIGH SPEED LINEAR THZ Imaging system is a perfect industrial inspection system developed by TERASENSE to help cut the number of such cases. Unwrapping a chocolate bar might reveal an unpleasant surprise like insects and pieces of metal or glass. Our High Speed camera Our HIGH SPEED LINEAR THz camera (and system) can easily do it, and would cost much less than the other counterparts in the market. Besides, our system can support conveyor speed up to 15 meter per second (= 900 m/min), which is a critical factor for Industrialists. The size of foreign bodies we can detect is also down to 1mm (which is determined by THz wave length at certain frequencies)	 *Layout for Linear Terahertz Imaging System installation on conveyor* HIGH SPEED LINEAR THz imaging system has already kindled the interest of Chinese and Korean OEM and we are discussing opportunities of marketing our products under white labels.
22.	***Pest control / insects control services – detection of pests*** Detecting termites and other insects (warms, bugs, larvae, maggots, slugs etc) inside the wood.	Our client from Middle East is considering introducing our products to the market.
23.	***THz microscopy - NDT testing*** Arts, painting, dactylographic analysis , dactyloscopy, fingerprinting THz microscopy of hand-written documents.	This application is demanding and still requires more R&D to study all the possibilities. We agreed that our client after purchasing of our THz imaging camera and conducting some test in this field will share his insights and results with us (just to evaluate feasibility)
24.	***3D THz tomography– Non-invasive (non-contact)***	We received several RFQs for our

	method for cancer identification Terahertz (THz) waves are being employed extensively in medical imaging applications, where conventional electromagnetic waves are not effective or unsafe (like X-rays). In particular, three-dimensional (3D) THz imaging or THz tomography has attracted a great deal of interest in various fields, such as medicine, pharmacy, security, and other industrial applications. 3D THz imaging (THz tomography) has recently proven to be useful for nondestructive testing of industrial materials and structures. Now medical sphere is catching up and actively exploring this opportunity. In place of previous imaging techniques in medicine such as THz pulsed/continuous-wave radar and THz computed tomography, 3D THz imaging is based on *THz optical coherence tomography* (OCT) technique using photonics- and electronics-based THz sources, and is set to demonstrate thickness measurement and tomographic imaging in frequency regions from 400 to 800 GHz.	TERA-series imaging cameras, which can be used as an element in *THz optical coherence tomography* set up. The whole assembly is called Terahertz swept-source optical coherence tomography (THz SS-OCT) system. Our experts arrived at conclusion that our THz imaging camera can be viewed as a potential replacement for *Schottky barrier diode (SBD) used in* THz SS-OCT. Once implemented, it may lead to a certain breakthrough in the field, because our THz camera may help considerably shorten the duration of 3D tomography process (i.e. increase the speed). The use of our TERA-1024 camera will allow to get rid of quite slow and unreliable method of mechanical scanning (on motorized stage performing the so-called raster scan)'. Our TERA-1024 THz imaging camera is believed to be a perfect fit for THz SS-OCT because it has built in modulation function (ON/OFF).
25.	***Lumbering (checking wood for knots and measuring knots)*** New sensor to help us detect defects that are difficult to detect using their current technology (color vision). One of these defect is the knots (some knots don't have color contrast, but the density of the knot is much higher than the wood surrounding it.	Terasemse has tested some wood samples and client is evaluating results (THz imaging pictures obtained) Terasense may need to conduct additional imaging at the TeraFAST-256-HS test bench using (on conveyor) which is being assembled
26.		

Not to mention hundreds of inquiries and orders from various R&D labs, scientific & research universities etc. from all over the world. They steadily rank high in our sales revenue by covering the overwhelming majority of the cases (while each case is absolutely unique and defies brief description).

It is truly gratifying to observe increasingly growing interest in T-ray technologies being displayed recently by many researchers, which very soon is expected to accentuate importance of THz imaging for industrial clients and OEM manufactures

As a responsible supplier committed to business ethics we don't think it would be appropriate to disseminate any information about our clients without their prior explicit consent. Such precautions make all the more reason considering that we have non-disclosure and Confidentiality Agreements signed with some of our clients.